TECHNICAL AND ECONOMIC FEASIBILITY OF A COGENERATION SYSTEM APPLIED TO HOTELS IN BRAZIL

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Abstract. A demand for finding solutions that can provide better energy use in hotel buildings is increasing, becoming something essential in the reality experienced in this sector in recent times around the world. An increase in energy efficiency of hotels through the application of cogeneration systems is a marked gain in competitiveness, becoming a decisive factor for guests and hotels' stakeholders, as well as a contribution to the sustainability of the enterprise.
In order to increase energy efficiency in hotel buildings, this paper aims to present the technical and economic feasibility of a cogeneration system using absorption refrigeration cycle applied to hotel air conditioning system. In the analysis performed in this paper, it took into account the sector's conditions in Brazilian cities, based on the fact that these cities receive an increasing number of tourists every year, both for cultural events and for business, and need to find solutions to reduce their electrical consumption.
Moreover, in recent years, Brazil has been experiencing a significant increase in the cost of electricity. The Brazilian energy matrix is still counting on a major portion of electricity generated by hydroelectric power plants, but the use of thermal power plants is increasing in this matrix, in order to offset the reduction in rainfall and the increasing demand of the country for electricity (due to larger industry demand and increasing electrification across the country). It is therefore necessary to seek alternative sources for energy production as well as encouraging the use of cogeneration systems through more efficient generation and energy conversion. Hotels have strong potential for application of cogeneration systems precisely because it has several energy appliances' needs (both thermal and electrical).
From the modeling of all components forming part of a cogeneration system such as the combustion chamber, turbine, steam boiler and absorption chiller, a study has been made using the variables that can provide a greater influence on the maximum condition efficiency of the system as a whole. It is noteworthy that climatic, seasonal factors, fluctuations in availability and cost of energy sources (whether renewable or not) are part of the local reality, and must be taken into consideration in this study.
For the scope of this paper, an absorption refrigeration cycle that uses a mixture of ammonia and water ($NH_3 + H_2O$) has been studied. The burning of liquefied petroleum gas inside the combustion chamber as a primary energy of the system was considered to meet the absorption refrigeration cycle demand for thermal energy inside the generator. Factors that may help to reduce the electrical consumption of the building will be presented, thus reducing the dependence of electricity and allowing the use of alternative fuels. In addition, the interactions between the various components that make up the cogeneration system, coupled with the varying energy consumption in a hotel building (such as HVAC, use of hot water in showers, electricity) will be assessed in order to optimize the energy efficiency of the whole building.

Keywords: cogeneration, optimization, absorption, refrigeration, hotel.

1. ACRONYMS

COP	Coefficient Of Performance	LPG	Liquefied Petroleum Gas
HVAC	Heating, Ventilation and Air Conditioning	TR	Tons of Refrigeration

2. INTRODUCTION

In the present scenario where the global economy is constantly growing, requiring more intensive use of natural resources for power generation and for the increase of production capacity, the discussion of what are the impacts of such scenario in the planet sustainability is important. Discussions deal on the availability of resources, on its divisions in renewable and nonrenewable resources, on the impact that the use of these resources generates and especially about what measures should be taken to avoid a catastrophic future.

A measure that has been used, taking into account the impact of the use of natural resources, is the rational use of energy. Several countries have adopted different strategies to encourage economic sectors to use the available energy more rationally. In Brazil, the Ministry of Mines and Energy (MME) created the National Program for Energy Conservation (PROCEL), today administered by Eletrobras. This program aims to promote the rational and efficient use of energy in different segments of society through the dissemination of qualified information on the topic (PROCEL, 2015).

Sustainability is a concept which has been discussed frequently and it is coupled with the issue of preservation of natural resources. This concept is being applied in different sectors of the economy, in order to reduce the impact generated by these sectors in our planet, and in order to enable future generations to continue taking advantage of all the available resources. Moreover, it is essential to address the rational and efficient use of energy.

Sustainability has been gaining a lot of space in recent years in the building industry. This sector consumes more than 30% of the energy matrix and more than 60% of the electricity used in the United States (USGBC, 2009), country that has one of the highest consumption of electricity per capita in the world (ANEEL, 2008).

A percentage of 52.6% of hotels and motels in southeastern part of Brazil have air conditioning systems installed, while in other commercial sectors, these percentages are much smaller, such as college and schools (9.8%), health services (10%), banks (8.2%), bakeries (2.6%) and clubs and associations (7.4%). In the case of a larger scale with various types of buildings, it is noted that the representation of the HVAC in the hotel industry is significant. Only in the southeastern part of Brazil, 52.6% of the hotels have air conditioning, while in the rest of Brazil, the percentage drops to 32.4% (EPE, 2011).

2.1. Objectives

The main objective of this paper is to study the technical and economic feasibility of a cogeneration system applied to a hotel located in the city of Sao Paulo, SP, Brazil. To fulfill this objective, it is necessary to establish a study of the energy consumption of hotels, already built and operating in São Paulo, to set a pattern of consumption of electric and thermal energy of these buildings. To illustrate the viability for this type of system, optimizations were made (based on the energy and economic criteria), as well as a sensitivity analysis to indicate parameters that guarantee the operation of this type of system.

The model and simulation of an absorption cycle using ammonia and water ($NH_3 + H_2O$) is done by a semi-empirical model, which uses as a heat source steam generated by a gas heater (which burns LPG). System parameters were identified in the analysis which could be modified in order to evaluate the whole performance. Thus, it is possible to evaluate the best combination of cold and hot water generation systems by combining the use of thermal loads with the ideal use of the electrical source.

2.2. Hotel Sector Scenario in Brazil

The hotel industry is a dependent construction market in relation to new projects and retrofits, with has high growth potential in Brazil, especially in periods when major events are held, such as the World Cup Soccer and the Olympic Games in the city of Rio de Janeiro. It is estimated that, in the years before the World Cup, the sector has increased by about 38,854 new rooms, whereas 238 new projects were launched, with the highest concentration of these hotels given to the cities that hosted the games (Hotelnews, 2012).

A hotel is a venture built and normally operated for profit, and so it must have a good management and financial administration to bring the expected return to their investors. Among other expenses, the energy bill is a major expense that will be managed by the building administration. The main energy consumption in a hotel is based on electric power and, depending on the type of water heating system, on thermal energy.

The consumption of a hotel can reach levels of 365 kWh/m² per year in large hotels (Bohdanowicz, et al., 2001). Considering a hotel with a total area of 20,000 m², and the price of kWh around R$ 0.30, the annual energy cost is close to R$ 2 million. With these data it is possible to have an idea of the importance of the right choice of systems that use energy efficiently. The main systems that generate energy consumption in a hotel are: air conditioning, elevators, lighting system and water heating system.

A hotel building has the peculiarity of a continuous operation (24 hours per day), besides being a very complex environment, given the diversity and quantity of functions performed by the set of complementary activities that take place on their premises. Hosting assumes adequate housing units, equipped with environmental comfort, thermal, acoustic, light and ergonomic, well-sized spaces, equipped and pleasant environments. It must also rely on administrative core activities of building systems, maintenance, as well as those related to the organization of events, recreation and leisure.

Such functional complexity requires a minimum investment to make the hotel project economically viable, resulting in a costly venture and a reasonable final cost of construction, operation and maintenance. In Brazil, it was the increased demand for travel and accommodation, triggered from the 1980s, which intensified the competition in the sector, thus determining the need to expand the operation scale, lower costs and diversified activities of local, in order to receive an increasing number of travelers, which started to move at a faster pace and more often.

In addition to this expansion of the travel and the incorporation of new segments of lower purchasing power market, there was a great growth in the events sector, which affected the increase in the share of new chains in the market, thus threatening the installed hotel. In Brazil, this advance was mainly in the major economic centers such as Sao Paulo and Rio de Janeiro.

The competitive strategies of international networks with strong brands, training programs with international standards, central reserves and capital available to low-interest has guaranteed the entrance in the Brazilian market, to a number of international economic brands. One of the characteristics of the economic value of a hotel brand in the Brazilian market is the low fare, as a result of facilities' optimization and a number of services reduced to the essential minimum for the guest to whom they are addressed, without jeopardizing the quality required for it.

According to estimates of the Brazilian Hotel Industry Association (ABIH), the hospitality sector has assets worth around US$ 10 billion and annual revenues of about US$ 2 billion, with an estimation of 25,000 lodging facilities in Brazil. The market leadership is up to the Accor® brand, which in 2010 had 23,000 rooms in Brazil; second place was awarded to Atlântica® with 12,000 rooms, followed by BHG® with 5,500 rooms. It was identified that 66% of hotels in number of rooms are independent, not participating to a franchise. Table 1 shows the number of hotel units classified by national, international and independent franchise (ABIH, 2016).

Table 1. Type and Quantity of Brazilian Hotels in 2010 (ABIH, 2016).

Type of Hotel	Number of Hotels	Market Participation (Hotel %)	Number of Rooms	Market Participation (Room %)
National Franchise	354	4	47,766	11
International Franchise	361	4	65,979	15
Independent Hotels with less than 20 rooms	3,486	37	38,518	9
Independent Hotels with more than 20 rooms	5,323	56	288,594	66
Total	9,524	100	440,857	100

2.3. LPG Market in Brazil

LPG is one of the by-products obtained from the refining of petroleum, and is predominantly composed of the mixture of the two hydrocarbons: Propane (C_3H_8) and Butane (C_4H_{10}). LPG is a stable liquid under pressures between 300 kPa and 1,000 kPa. This facilitates their storage and use in different sectors and end users. Some important features may be mentioned, such as the high energy power and the easy operation from the smallest household appliance up to large industrial facilities. Moreover, since LPG is a cleaner fuel than other oil by-products, LPG can be used in direct contact with food and items such as fine ceramics, without prejudice to the purity and quality of these products.

Brazil is the fifth largest LPG consumer market in the world, with an annual consumption of 7 million tons in 2010, behind of the USA, Japan, China and Mexico (EPE, 2011). In Latin America, Brazil stands as the second largest consumer, with only Mexico with a higher consumption, which stood at 9 million tons. In Brazil, LPG has a residential, commercial and industrial usage. Recently, there was a very strong incentive from the Brazilian government to the growth of natural gas and LPG in the Brazilian energy matrix in all segments.

LPG has an important role in the Brazilian energy matrix and the economy. For various reasons, it became known only as a "cooking gas" and thus is sometimes underestimated in their ability to participate in the energy matrix for noble uses. Nowadays LPG can fully meet local consumption, and it may be used in new applications, like cogeneration.

3. METHODOLOGY

The methodology applied in this paper can be summarized in the following steps:

- Definition of characteristics of the hotel used as reference
- Evaluation of the electrical energy and heating demand profiles
- Evaluation of the main operation parameters
- Development of the model for the refrigeration and cogeneration systems
- Model simulation and analysis of the results

3.1 Characteristics of the Reference Hotel

In this work, the reference model is a hotel which is considered as a market standard in the city of Sao Paulo. The number of rooms in the same area and usage pattern were taken from some of the Ibis Budget® brand hotels (Accor®): the buildings are considered medium-sized (around 300 rooms) and have low cost for the end hosting. It was decided to use the data from an unit located in a central part of São Paulo The services offered by these hotels are similar to each other: breakfast, lunch, dinner, room service 24 hours a day, and count on meeting rooms, auditoriums, business center room, among others. As for recreation and leisure services, much of it has a gym, sauna and a swimming pool.

Through the analysis of the energy matrix in a hotel, it is possible to identify variations due to the characteristic of usage, such as business hotels, weekend, events and others. The percentage distribution of electricity demands for the hotels of Ibis Budget® franchise in the city of Sao Paulo are shown in Figure 1. For the hotel sector, water heating and air conditioning counts for about 42% of total electricity demand of the building, converging especially during peak hours, time in which these systems are used in greater intensity (Ibis Budget® Franchise, 2016).
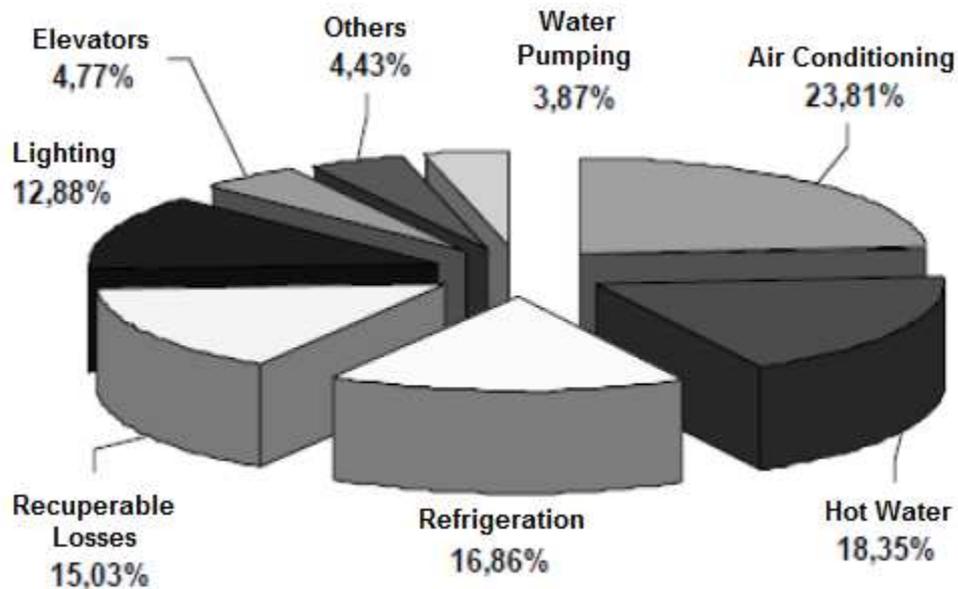

Figure 1. Percentage Distribution of Electricity Demand in Hotels Located in Sao Paulo, Brazil
(Ibis Budget® Franchise, 2016).

3.2 Current Conventional System (CS) for Air Conditioning and Hot Water Distribution

The current configuration of the conventional system of hot and cold generation sources applied to the hotel is completely independent, and it does not exploit the thermal waste. The system for heating water is composed by 8 (eight) heat exchangers of 25.6 kW, with 2 (two) of these operating as backup, and 6 (six) operating continuously (total power of 153.6 kW). Also, there is 1 (one) 3,000 liters hot water reservoir.

The chilled water come from 2 (two) electric chillers, with 1 (one) equipment working as backup. The configuration of the conventional system provides hot water power of 153.6 kW and cold source power of 950 kW, and the scheme is shown in Figure 2.
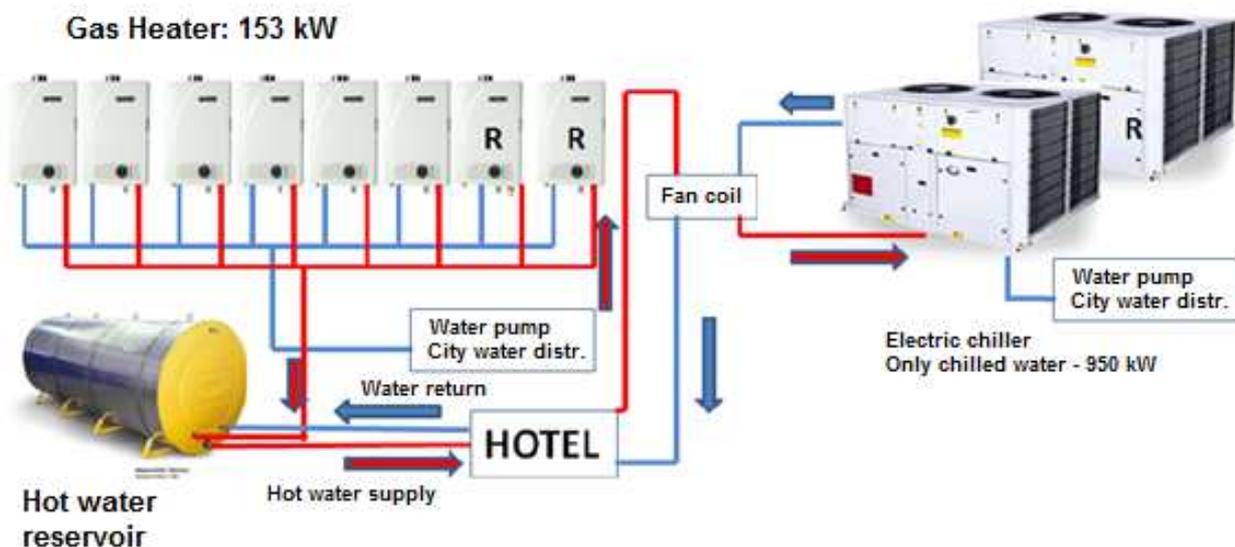

Figure 2. Configuration of the Conventional System (CS).

3.3 Proposed System (PS) of Air Conditioning

The proposed system combines energy sources and equipment with the best efficiency and economy. The vapor compression chiller (powered by electricity) is combined with a small absorption chiller (fed by hot water). The heating water system is fully powered with liquefied petroleum gas, combining the hot source of the small chiller system, and a backup heater system.

The synergy of this system converges to the best practice in the area of energy efficiency, due to the reduced consumption of energy inputs for generation of hot and cold sources. In order to adapt the best ratio of the number of small absorption chillers, it was necessary to perform calculations for the pursuit of optimum consumption of energy inputs involved and its costs. The best configuration was identified through a simulation of three models, varying the power of a small absorption chiller and consequently adjusting the power of large chiller, as shown in Table 2.

Table 2. Power Supplied by Each Configuration of Proposed System (PS).

Configuration	Option #1	Option #2	Option #3
Hot water source (kW)	116	272	504
Chilled water provided by main electrical chiller (kW)	897	827	721
Chilled water provided by small absorption chiller (kW)	53	123	229

The hot water demand is the determining factor for the system design. An increase in power of the small absorption chiller causes a considerable increase in the generation of hot water. The choice for Option #1 can be justified by the analysis shown in Table 3: as the number of small absorption chiller raises, the generation of hot water starts to consume more LPG, becoming ineffective for the purpose of this analysis.

Table 3. Cost Comparison for Each Configuration of Proposed System (PS).

Configuration	Expenses (R$/year) for Hot Water (LPG Consumption)	Expenses (R$/year) for Chilled Water
Conventional System (CS)	83,592	551,237
Proposed System (PS) – Option #1	44,064	431,516
Proposed System (PS) – Option #2	102,816	430,134
Proposed System (PS) – Option #3	190,444	419,351

The configuration of the Proposed System (Option #1) can be considered the most economic feasible. Based on a market comparison of each energy cost, it is possible to have the total savings for each system. The total energy expenditure of the proposed system was compared with the conventional system in order to identify the biggest savings achieved, as shown in Table 4.

Table 4. Comparison of Proposed System (PS) Savings.

Configuration	Total Energy Expenses (R$/year)	Savings (R$/year) Compared to the Conventional System (CS)
Conventional System (CS) – 950 kW	634,829	-
Proposed System (PS) – Option #1 – 897+53 kW	475,580	-159,249
Proposed System (PS) – Option #2 – 827+123 kW	532,950	-101,879
Proposed System (PS) – Option #3 – 721+229 kW	610,295	-24,534

The proposed system, option #1 (PS1), shown in Figure 3, provides 97 kW of hot source and 950 kW of cold source: the large electric chiller provides 897 kW and it is complemented with 53 kW from a small absorption chiller (considering the LPG as its energy input). The hot water receives heat from the small absorption chiller, and also from 1 (one) heater of 105 kW, installed as a backup. Also, there are 2 (two) tanks of 3,000 liters each, designed for hot water storage. The chilled water is provided by 2 (two) electric chillers, one of these works as a backup equipment, and 4 (four) absorption chillers each equipment with a capacity of 17.6 kW, one of these is installed as a backup.
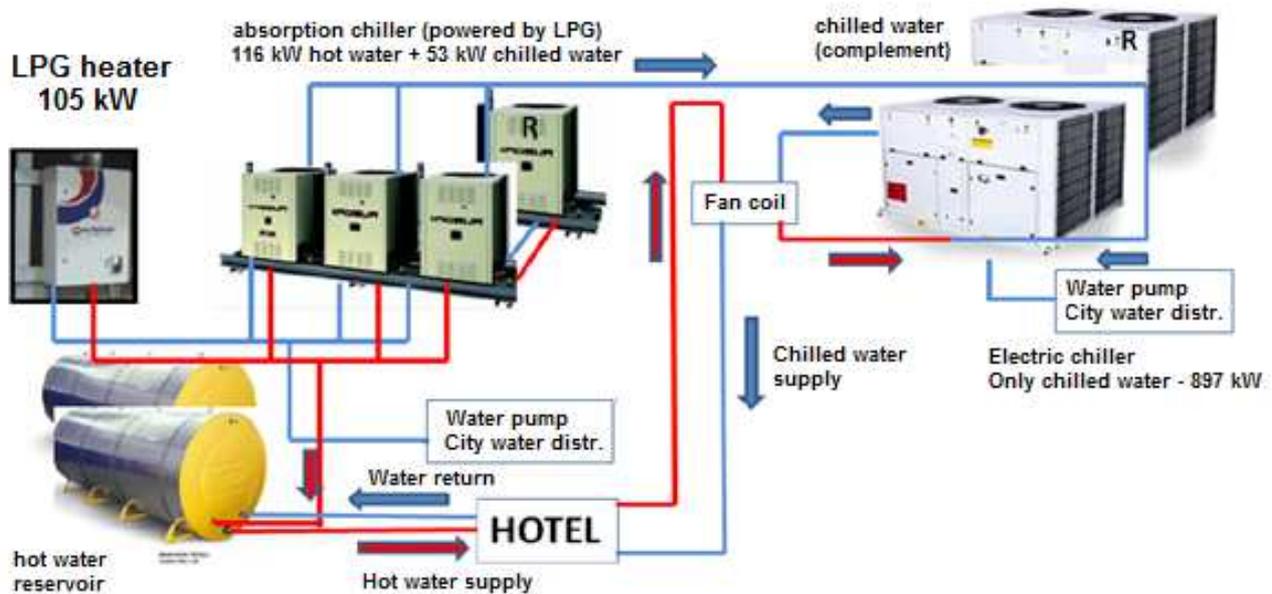
Figure 3. Configuration of the Proposal System (PS).

In order to achieve an ideal balance of the system, the operation of the small absorption chiller is used as a priority, and according to the demand increase, the electric chiller comes into operation.

4. SIMULATION AND MODEL EVALUATION ANALYSIS

4.1 Total Energy Consumption

Using the models proposed previously presented, a performance analysis was made, and some adjustments in the parameters were done to achieve the objective of reducing the energy consumption of the hotel.

Table 5. Annual Total Energy Consumption (in kWh).

	Hot Water Annual Consumption		Chilled Water Annual Consumption	
	Conventional System	Proposed System	Conventional System	Proposed System
Energy Consumption (kWh)	431,568	227,493	1,312,470	1,085,104
Savings using Proposed System	-204,075 (47%)		-227,366 (17%)	

A reduction of 47% in the hot water system and a 17% savings in the chilled water system were achieved. It is noteworthy that the biggest difference obtained in the hot water system is due to the combination of generation sources resulting from use of thermal waste of the small absorption chiller. The reduction evaluated in the chilled water system is identified by relieving the electrical chiller, due to the small absorption chiller operation, thus seeking the best efficiency and operating flexibility between both systems.

4.2 Total Cost of Fuel and Electricity

The annual cost of fuel and electricity is shown in Table 6, related to each source of energy. The cost of electricity for a hotel in the city of Sao Paulo has been fixed in R$ 0.42 per kWh, and the LPG cost has been fixed in R$ 2.50 / kg of fuel. The usage factors considered (percentage of hours of usage per day) were 30% for hot water and 50% for chilled water.

Table 6. Annual Total Cost of LPG and Electricity.

	Hot Water Annual Cost		Chilled Water Annual Cost	
	Conventional System	Proposed System	Conventional System	Proposed System
Annual Cost (R$)	83,592	44,064	551,237	431,516
Savings using Proposed System	-39,528 (47%)		-119,721 (22%)	

This analysis has identified a cost reduction in order to have hot water of 47%, and a cost reduction for the chilled water of 22%, due to the consumption and the values of energy inputs involved (electricity and LPG).

4.3 Comparison Between Conventional and Proposed System

A comparative consumption and total energy expenditure between the configurations was conducted to understand the impact of the whole system, and this can be seen in Table 7.

Table 7. Total Energy Consumption and Cost Comparison.

	Conventional System	Proposed System	Savings using Proposed System
Energy Consumption (kWh)	1,744,038	1,312,597	-431,441 (25%)
Annual Cost (R$)	634,829	475,580	-159,249 (25%)

A 25% reduction in energy consumption and total cost has been achieved, consolidating the proposed reduction in the consumption of energy inputs. This leads to a potential application of the Proposed System in a hotel building.

5. CONCLUSIONS

Energy consumption in the commercial sector (including hotels) and scenarios of electricity generation can be concluded that the direct use of fuels can contribute to energy rationalization in Brazil. Electricity is a form of high-quality energy and should therefore be designed to noble applications, i.e. where it cannot be replaced by another energy source.

The hotel industry has been growing in its occupancy rate and may require supplementation in air conditioning systems and hot water, requiring analysis of investments to consider spending on energy inputs involved. The configuration of the Proposed System presented in this work is recognized in the regulation of PROCEL in topic "Efficient Buildings" for the commercial sector to generate hot and chilled water, contributing to improved ranking in the labeling of the building system.

The combination of hot and chilled water generation through the use of LPG results in a reduction in energy consumption during peak hours, and the expansion of this application would contribute considerably to the reduction of heavy investments in the generation, transmission and distribution of energy electric. Despite the lower financial costs for the Proposed System, it appears that the technology is not very widespread commercially. It is possible to name a few difficulties for the expansion, such as a reduced technical assistance network and national sales representatives, equipment import time (and relative bureaucracy associated), and even a certain lack thereof by stakeholders.

Suggestions for future work can be named, such as conducting heating studies of water through solar panels, enabling a significant reduction in energy consumption. Another interesting point to be compared with the economic analysis, which is often widely analyzed in European countries, is a reduction on the gas emission that causes the so-called "greenhouse effect" on the planet.

The economic impact of the proposed solutions in the hotel model could also be assessed in future papers. A return on investment analysis (pay-back) can be performed according to the viability of the set of solutions adopted. This return of expenses related to the project is the determining factor to cause an improvement in construction, and that will likely be considered by the owner of the building according to the socioeconomic, political and environmental aspects of the area that the hotel belongs.

The characterization of the hotel (for weekend events, weekend events, business, tourism, resorts, etc.) can influence the demands of hot and chilled water, and serves also to identify the breakeven point for the number of equipment to be used. Some limitations to this type of research require an extensive survey, which takes into account a database for several hotels in various regions of Brazil, identifying their climate variations over a long period of time to carry out more faithfully the load of the hot and cold sources.

The development of a quantitative expanded regulations regarding the use of a broader concept of energy efficiency would quantify the primary energy consumption, and thus identify which technological routes and the most appropriate energy inputs for useful energy production, characterizing as well as an important tool for energy efficiency policies.

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