

ANALYSIS OF THE CRITERIA FOR DESIGNING, INSTALLING AND OPERATING A COGENERATION SYSTEM

Alcir de Faro Orlando, PhD, e-mail afo@mec.puc-rio.br
Pontificia Universidade Católica do Rio de Janeiro – PUC-Rio, R. Marquês S.Vicente 225, Rio de Janeiro, Brazil

Luiz Gustavo do Val, MSc, e-mail ldoval@ituc.puc-rio.br
Pontificia Universidade Católica do Rio de Janeiro – PUC-Rio, R. Marquês S.Vicente 225, Rio de Janeiro, Brazil

Abstract. *Cogeneration is defined as the use of the chemical energy of a given fuel to sequentially produce work and thermal energy, or vice-versa, thus increasing the efficiency of the energy utilization in the whole process. The design of the system starts by specifying the electric energy load. It can be obtained from the utility company for a one month period, every 15 minutes, by acquired data, or by estimates. This works suggests how to extrapolate the data for the whole year. The thermal energy load can be obtained by running available air conditioning softwares, by specifying the steam needs, or by typical estimates for the sector, which includes hypotheses on the usage of the available air conditioning equipments. This work rationally discusses the methodology to be used in the analysis. Sizing the equipments to be used and their number is another matter to be discussed, which goes through their efficiency under partial and full load operation and the convenience of using partially the available energy from the local utility company. The cost of the equipments, the actual electric energy and fuel tariffs, the maintenance costs and the duration of the system operation over the day are parameters to be used in the cost benefit analysis, which results in calculating the payback and the internal rate of return of the investment. Usually, the cogeneration system is not specified for attending full load. Installation is another matter to be discussed, because it can increase the investment in the cogeneration system. Parallelism to grid is another discussed subject, detailing the protection relays and equipments, as required by the utility company. Finally, this discussion is supported by detailing the analysis of a 3000 kVA diesel system, designed to supply energy to PUC-Rio.*

Keywords *: Cogeneration, Energy Supply, Economic Feasibility, Design Criteria*

1. Introduction

The decision of choosing an electric energy generating system (genset), or a cogeneration system, for supplying energy to an institution, in place of the energy presently supplied by the local utility company , is usually done on an economic basis. Eventually, security or reliability reasons can be important in the decision. The genset usually burns natural gas or diesel fuel. The calculating procedure is straightforward (Orlando,1996; ASHRAE,2000)) and usually starts by identifying the actual cost of energy, as presently bought from the utility company, and comparing it to the proposed one. An initial investment has to be made on the energy system, which must be paid by the financial savings that result from the use of natural gas or diesel, which replaces the electric energy presently purchased. Economic parameters are then calculated, like payback and internal rate of return (IRR) of the investment, which are compared to the values that are presently available to the institution , if it wants to make financial applications in the stock market or any banking product, besides investment in its own activity production.

Electric energy tariffs, as charged by the utility company, vary with the period of the day (peak and off peak) and period of the year (dry and humid), being cheaper for higher voltage supply, which requires investment in transformers. The overall cost of the purchased electric energy depends basically on two parameters, (a) Maximum instantaneous power that occurred over a one month period (for peak and off peak periods), and (b) Energy consumed over a one month period (for peak and off peak periods). The utility company calculates the instantaneous power as the averaged power over a 15 minute period. Therefore, the operational cost of the present and proposed systems must be compared at each period, separately., in order to determine the cost benefit.

The starting point for this analysis is the institution electric load profile. Ideally, if one has the instantaneous power profile for all days of the year, that is, averaged power every 15 minutes in the year, it is possible to calculate the electric energy cost, as purchased from the utility company. Energy consumption can be calculated by integrating this profile over a given period. This profile was available to PUC-Rio, and it was used as a baseline for the developed methodology. However, this information is seldom available. Rather, the utility company supplies, under request, the load profile for the last month of operation, only. When charging monthly for the purchased electric energy, the utility company informs the maximum instantaneous power and the energy consumed for peak and off peak periods, over a one month period.

Therefore, the institution usually has a monthly record of the billing information for a one year period and the electric load profile for a one month period. A methodology was developed to extrapolate the available information for the whole year. It was validated by comparing the results with the baseline simulation of PUC-Rio.

Air conditioning in an institution is a big consumer of electric energy, when an electric chiller is in operation. Sometimes it is cheaper to switch to an absorption chiller that needs heat from burning fuel for its operation. Usually, steam generated in a boiler is used to supply heat to the chiller. Sometimes direct fired chillers are specified. The chiller itself is less efficient and more expensive than the electric ones. However, because the fuel can be cheaper, the operation cost can be lower. In order to quantify the contribution of the air conditioning load to the total electric energy consumption, and then to calculate the absorption chiller fuel consumption and cost, a methodology was developed

Gensets are about 30% to 40% efficient, meaning that the difference to 100% is wasted as heat to the atmosphere. In order to reduced the cost of producing steam, either to feed the absorption chiller, or to use it as a heat transfer vector, the waste heat transferred in a recovery boiler prevents burning fuel, thus reducing the overall operating cost of the energy plant. This process is known as cogeneration, which is defined as the use of the chemical energy of a given fuel to sequentially produce work and thermal energy, or vice-versa, thus increasing the efficiency of the energy utilization in the whole process.

The objective of this paper is to describe a methodology to estimate the electric and thermal loads of a plant, and to calculate the economic parameters, so that the cost benefit of replacing the purchased energy from the utility company for gensets or a cogeneration system can be evaluated. A software, containing a data bank for performance and cost of equipments, was developed for LIGHT/ANEEL to make all the calculations. Some examples are given to detail the methodology.

2. Methodology

2.1. Electric load profile especification

The methodology requires that an electric load profile (average power every 15 minutes) be available for one given month, called reference month, as obtained from the utility company records. Similar profiles are respectively generated for each of the remaining months of the year, multiplying each value of the average power in the reference load profile by the ratio between the consumed energy in a certain month and the consumed energy in the reference month, as available to the institution from the monthly electric energy billing records. In case the load profile is not available every 15 minutes, an interpolation scheme generates a load profile every 15 minutes. Also, if the electric load profile is not available from the utility company, a typical daily load profile must be available from literature for similar business, or from the designer experience. An interpolation scheme must provide the data every 15 minutes. There must be a compatibility between the consumed electric energy, as supplied by the utility company, and the calculated one, obtained by the profile integration.

When cogeneration is examined, the electric chiller is replaced by the recovery boiler and the absorption chiller. Some of the equipments may remain the same, like chilled and condensing water pumps, or fan coils. Boiler feedwater pump must be added. The cooling tower electric energy consumption can be higher because of its larger capacity. The electric energy consumption for each configuration must be estimated, so that reduction in electric energy consumption (mainly electric chiller) can be deducted from the electric load profile, as established before. This will be the new electric load profile (average power every 15 minutes).

2.2. Thermal load profile especification

Most possibly, there will not be available a thermal load profile (average cooling load, kW or TR, every 15 minutes). However, there are some alternatives to supply the information :

- Measure over a one month period the electric load, every 15 minutes, of the chiller and support equipments. Knowing the chiller coefficient of performance (COP) from manufacturer especification, it is possible to calculate the cooling load, kW, every 15 minutes.
- Use available air conditioning load computer programs, and calculate monthly average cooling load, kW or TR, as a function of the time of the day. Monthly average thermal load profiles, every 15 minutes, can be generated by an interpolating scheme.
- Use typical daily load profile available from literature for similar business, or from the designer experience. Monthly average thermal load profiles, every 15 minutes, can be generated by an interpolating scheme.
- Get an electric load profile (average power, every 15 minutes) from utility company for a one month period, after having set, during this period, a procedure for turning on and off all the electric equipment load, so that the contribution of the chiller to the total electric load can be estimated. Knowing the chiller coefficient of performance, it is possible to calculate the thermal load , kW or TR, at this time. It is preferable to choose the time of the day where each load can be separated. This paper deals with this methodology.

The methodology that was developed starts by identifying all the nominal electric power values of all equipments that consume electric energy. Assume that when those equipments are on, they do operate at nominal power. Chiller must be an exception to this rule, because they operate at partial load. Upon examining the electric load profile every 15 minutes, it is possible to deduct the total power due to all loads at constant power from the total value, resulting, by difference, in the chiller power. Knowing the chiller coefficient of performance, it is possible to calculate the thermal load, kW or TR. This methodology works better for the following conditions :

- When typical loads like lights, pumps and fans do operate continuosly during the day, being considered as constant. In other words, on and off periods of time are known most precisely. When this information cannot be obtained easily, it must be estimated from the load profile, by turning on and off the equipments at selected times of the day.
- The procedure used to turn on and off the loads clearly separate different loads. Naturally, this experimental procedure cannot interfere with the institution life.

- If the operating conditions start varying, the reliability of the results is higher for the total monthly value, and not the daily value. In this case, one is satified with the monthly consumption of energy, or fuel, exactly at billing dates.

As an example, Table 1 presents the nominal capacity of the equipments in a commercial building, located in the city of Rio de Janeiro. Fig. 1 shows a typical electric load, with turning on and off equipments.

Table 1 : Nominal capacity of equipments

Equipment	Load (kW)
Chiller	967,2
Fancoil	313,5
Self Contained	173,5
Multi Split	68,7
Cold Water Pump	88,3
Condensing Water Pump	66,2
Cooling Tower	58,9
Internal Lights Installed	1223,0
External Lights Installed	39,1
Elevators	530,0

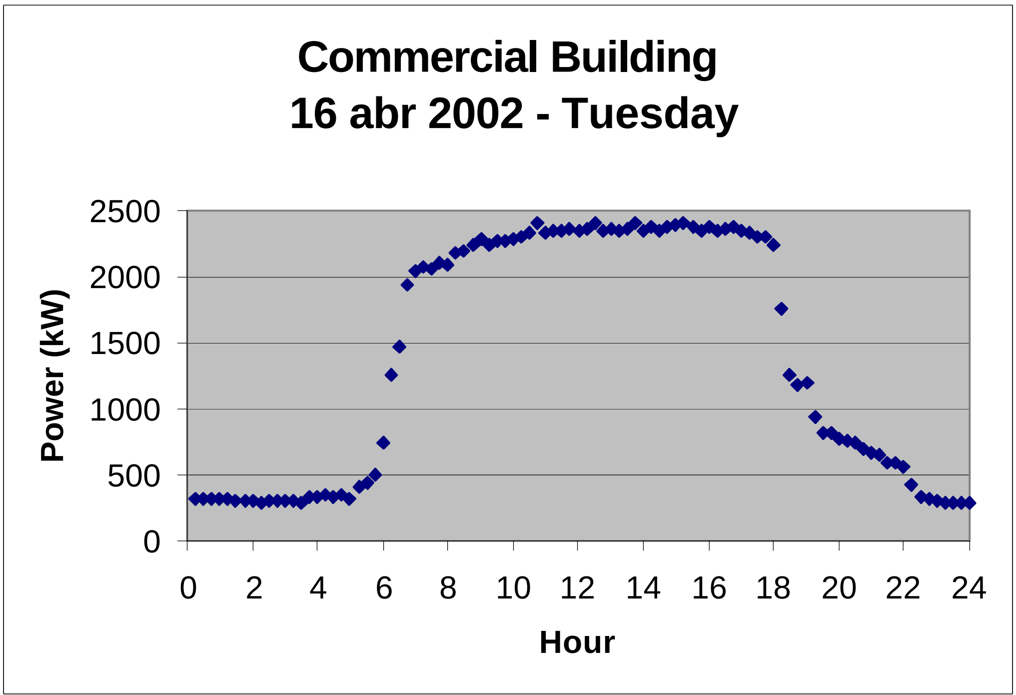

Figure 1 : Typical load profile

Although the nominal capacity of the installed equipments is given by Table 1, and considering that not all equipments are turned on, or at full power, at each instant of the day, the energy consumed by each one was obtained from the analysis of the load profile, that was done with the following information, with each item number associated with the hour of the day (for example item 2 refers to 4:00 h) :

Item 1 0:00 h : Only critical lights are turned on (minimum consumption). Room lights, Self Contained, Multi Split and Elevators are turned off. Chiller can eventually be, partially or totally, turned on. The load profile indicates this feature.

Item 2 4:00 h : Chiller are turned on at full load.

Item 3 6:00 h : Room lights are turned on, for building cleaning purpose.

Item 4 8:00 h : Beginning of the working period. People start getting in. Self Contained, Multi Split and Elevators start operation.

Item 5 13:00 h : All equipments working at peak load. Maximum air conditioning load.

Item 6 17:30 h : Peak period, for billing purpose, starts at this time.
Item 7 18:00 h : Chiller is turned off. Cold water pumps are still on. Self Contained and Multi Split start being turned off. End of the working period. Most people leave the building.
Item 8 19:00 h : Cold water pumps are turned off. Self Contained and Multi Split turned off. Lights start being turned off. Elevators turned off.
Item 9 20:30 h : Peak period, for billing purpose, ends at this time.
Item 10 22:00 h : Room lights turned off. Only critical lights on. Chiller can eventually be turned on. The load profile indicates this feature.
Item 11 24:00 h : Chiller can eventually be turned on. The load profile indicates this feature.

The following data can be obtained from the load profile, by simply reading the power at the time of the day

Table 2 : Power as a function of time and day (kW)

	POWER AS A FUNCTION OF TIME AND DAY (kW)											
HOUR	22:00	0:00	4:00	6:00	8:00	13:00	17:30	18:00	19:00	20:30	22:00	24:00
ITEM	10	1	2	3	4	5	6	7	8	9	10	11
10/APR	449	340	323	1901	2045	2362	2229	2189	852	697	346	346
11/APR	346	328	328	1889	1941	2356	2252	2206	881	743	495	357
12/APR	495	351	386	1786	2022	2390	2177	2120	847	726	409	323
16/APR	484	311	323	2039	2097	2408	2304	2241	818	737	334	288
17/APR	334	288	276	1970	1999	2448	2298	2241	835	708	397	340
18/APR	397	323	351	1912	2218	2471	2310	2246	852	732	564	334
19/APR	564	323	311	2039	2223	2408	2229	2183	812	680	357	317
24/APR	300	616	1475	2045	2079	2477	2298	2298	824	714	323	311
25/APR	323	323	300	1981	2102	2425	2310	2310	847	749	363	346
26/APR	363	346	369	2004	2160	2419	2269	2235	841	737	386	317
29/APR	311	1354	1319	1935	2074	2344	2189	2166	858	697	415	323
30/APR	415	317	305	1981	2137	2413	2258	2172	829	720	357	311
2/MAY	305	305	305	1763	1901	2252	2160	2074	876	737	374	357
3/MAY	374	346	340	3039	2120	2419	2252	2200	795	680	346	311
6/MAY	282	369	835	1693	2056	2425	2287	2287	852	720	403	369
7/MAY	403	363	380	2016	2068	2408	2160	2102	864	708	420	328
8/MAY	420	328	328	1935	2051	2419	2327	2269	852	732	351	323

Table 3 :Equipment estimated power at maximum load (kW)

DAY	EQUIPMENT ESTIMATED POWER AT MAXIMUM LOAD (kW)									
	A	B	C	D	E	F	G	H	I	J
10/APR	449	1452	144	593	317	66	88	59	314	925
11/APR	346	1543	52	398	415	66	88	59	314	1016
12/APR	495	1291	236	731	368	66	88	59	314	764
16/APR	484	1555	58	542	311	66	88	59	314	1028
17/APR	334	1636	29	363	449	66	88	59	314	1109
18/APR	397	1515	306	703	253	66	88	59	314	988
19/APR	564	1475	184	748	185	66	88	59	314	948
24/APR	300	1745	34	334	398	66	88	59	314	1218
25/APR	323	1658	121	444	323	66	88	59	314	1131
26/APR	363	1641	156	519	259	66	88	59	314	1114
29/APR	311	1624	139	450	270	66	88	59	314	1097
30/APR	415	1566	156	571	276	66	88	59	314	1039
2/MAY	305	1458	138	443	351	66	88	59	314	931
3/MAY	374	1665	81	455	299	66	88	59	314	1138
6/MAY	282	1411	363	645	369	66	88	59	314	884
7/MAY	403	1613	52	455	340	66	88	59	314	1086
8/MAY	420	1515	116	536	368	66	88	59	314	988
Average	386	1551	139	525	327	66	88	59	314	1024
%				21,8	13,6	2,7	3,7	2,5	13,1	42,6

The equipment estimated power at maximum load (A,B,…,I,J columns), for each measured day, is calculated using data from Table 2 (1,2,…,10,11columns). The following calculation procedure was used :

- A) Critical lights on, read directly from the load profile, item 10 (first column, day before)
- (B) Full load Chiller power + Condensation water pump power+ Cold water pump power + Cooling tower fan power + Fancoil power = Item 3 – Item 10
- (C) Room light power = Item 4 – Item 3
- (D) Total light power = Item 10 + C
- (E) Self Contained power + Multi Split power + Elevator power = Item 5 – Item 4, variable partial load power
- (F) Condensation water pump power = From Table 1, constant power when on.
- (G) Cold water pump power = From Table 1, constant power when on
- (H) Cooling tower fan power = From Table 1, constant power when on
- (I) Fancoil fan power = From Table 1, constant power when on.
- (J) Chiller power = B – (F+G+H+I)

It can be seen that powers A, C, D, E and J are variable , and an average value has to be calculated for the month. Powers F, G, H and I are constants. The chiller power at full load is close to the nominal value (5,9%).

Considering that D, F, G, H and I are constant (light profile does not very much along the month), when the power is on, the energy consumption along the month can be calculated multiplying this value by the numbers of hours they are on in the month, as seen from the load profile. Summing up all the constant power contributions to the energy consumption, and subtracting from the total energy consumption in the month, one can get the sum of electric energy consumption of the chiller, self contained, multi split and elevator during the month. The contribution of the elevators to the energy consumption can be estimated from the daily numbers of people that uses the elevators and from the number of hours they are on and must be deducted from the last value. The electric energy contribution of each type of air conditioning equipment is now supposed to be proportional to its nominal power in Table 1.

Knowing the coefficient of performance (COP) for each equipment, it is possible to estimate the cooling load along the month in TR.h/month.

However, the electric load profile is available for only one month. Monthly energy consumption is available for 12 months, from the billing information. Considering that in this commercial building electric loads but air conditioning load are constant along the year, one can every month calculate the contribution of each type of air conditioning equipment to the electric energy consumption, and, therefore, the cooling load in TR.H/month.

This procedure can be followed for peak and off peak periods, and the results are indicated in Tables 4 and 5.

Table 4 : Air conditioning cooling load (TR.h)– Peak period

Month	Year	Electric Energy Consumption			Cooling load		
		Total	Equip.	Air Cond	Chiller	SelfMulti	Total
		kWh/mo	kWh/mo	kWh/mo	TR.h/mo	TR.h/mo	TR.h/mo
January	2002	73809	55599	18210	14564	2918	17481
February	2002	83421	55599	27822	22251	4457	26708
March	2002	58814	55599	3215	2571	515	3087
April	2002	80228	55599	24629	19697	3946	23643
May	2002	82544	55599	26945	21549	4317	25866
June	2002	73022	55599	17423	13934	2791	16726
July	2002	68844	55599	13245	10593	2122	12715
August	2002	78575	55599	22976	18375	3681	22056
September	2002	79937	55599	24338	19464	3899	23364
October	2002	77227	55599	21628	17297	3465	20762
November	2002	81504	55599	25905	20717	4150	24868
December	2002	79556	55599	23957	19160	3838	22998
Average		76457	55599	20858	16681	3342	20023

Table 5 : Air conditioning cooling load (TR.h)– Off Peak period

Month	Year	Electric Energy Consumption			Cooling load		
		Total	Equip.	Air Cond	Chiller	SelfMulti	Total
		kWh/mo	kWh/mo	kWh/mo	TR.h/mo	TR.h/mo	TR.h/mo
January	2002	659952	443323	216629	173246	34707	207953
February	2002	669456	443323	226133	180847	36229	217076
March	2002	572688	443323	129365	103458	20726	124184
April	2002	677232	443323	233909	187065	37475	224540
May	2002	727200	443323	283877	227027	45480	272507
June	2002	696384	443323	253061	202382	40543	242925
July	2002	629424	443323	186101	148832	29816	178647
August	2002	673488	443323	230165	184071	36875	220946
September	2002	704448	443323	261125	208831	41835	250666
October	2002	666432	443323	223109	178428	35745	214173
November	2002	694800	443323	251477	201115	40290	241405
December	2002	688608	443323	245285	196163	39298	235461
Average		671676	443323	228353	182622	36585	219207

2.3. Operating cost

The operating cost of an energy system must be computed by quantifying (a) The purchased electric energy from the utility company, (b) The purchased fuel (diesel, fuel oil, LPG, natural gas) to be used in heating applications, boilers, chillers, engines or gensets, and (c) O & M costs.

The methodology for calculating electric energy cost follows ANEEL (2002). Tariffs are yearly updated. Natural gas tariffs are much lower for generation or cogeneration than for other heating applications. Diesel tariffs usually follows the values the fuel supply stations buy from the fuel supplier, today about R$ 1,30/l (US$ 0,43/l).

O & M cost must be computed using maintenance contract values for each equipment. Orlando (1996) suggests the following values for gensets, (a) US$ 0,015/kWh for natural gas engines, OTTO cycle, (b) US$ 0,005/kWh for natural gas turbines. Diesel genset operating cost can be about US$ 0,020/kWh, according to the information obtained in the Brazilian market.

In order to calculate the purchased electric energy cost, it is necessary to have the information on the monthly consumption and on the maximum power that occurred in the month, for each period, peak or off peak.

Fuel consumption for heating applications can be determined from the thermal load and from the equipment efficiency. Boilers usually operate with an efficiency (with respect to fuel high heating value) in the 80 to 85% range.

Electric chillers for air conditioning may consume at full load 0,55 kW/TR for the centrifugal type, and 0,94 kW/TR for the screw type. Self Contained and Multi Split units may consume about 1,20 kW/TR.

Absorption chillers have a coefficient of performance of 0,65 when single stage and 1,05 when double stage.

Diesel gensets consume about 0,27 l/kWh. Natural gas alternative engine gensets consume about 0,30 Nm^3/kWh. Natural gas turbine gensets consume about 0,33 Nm^3/kWh.

2.4 Sizing gensets

Usually, a genset or a cogeneration system is not economically specified to attend the full load. Therefore, the genset must be in parallel to the grid, so that the utility company supplies the difference, when the load is larger than the genset full load capacity. When the capacity is specified to attend the full load, as seen in the billing records, the equipment investment cost is higher, and the genset operates in partial load most of the time, which makes the energy cost higher. It can be estimated by varying the genset capacity, and calculating the amount of energy that is produced by the genset and the one bought from the utility company to complement the energy needs. Considering, as a reference, that the electric energy is presently supplied by the utility company, an investment must be made on the genset, that operates at a lower cost, thus defining the rate of return of investment (IRR). The genset size can be determined as the one that maximizes the IRR.

Figure 2 presents the variation of the IRR with microturbine genset power, which will be installed in a fuel supply station that has a maximum load of 400 kW. It can be seen that the maximum IRR is in the 240 to 300 kW capacity, respectively 60% to 75% of the full load.

As an average cost, diesel gensets can be bought in Brazil (SIF) for about US$ 300/kW, in a turnkey operation. Natural gas alternative engines and turbines, for US$ 750/kW. Dual fuel for US$ 360/kW.

Parallelism to the grid requires a project to be approved by the utility company, together with the installation of protection relays and other equipments, so that the utility company be protected from the introduction of bad signals into the grid. Cost can be in the US$ 20000 to US$ 30000 range

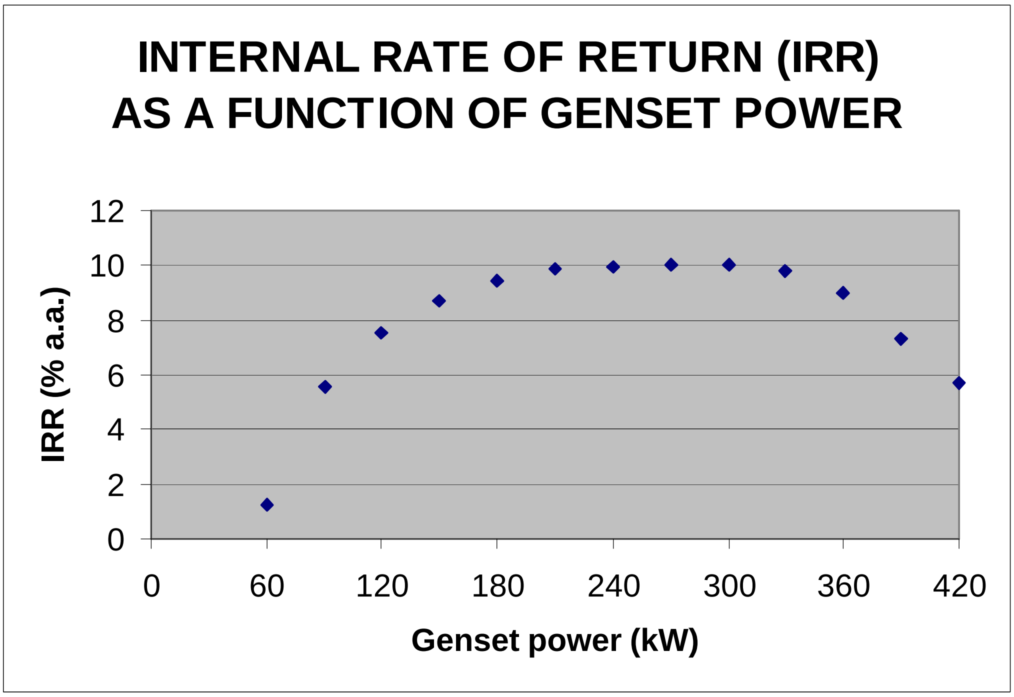

Figure 2 : Cost benefit analysis of a microturbine genset in a fuel supply station

Orlando (1996), presents an estimate of the average cost of a cogeneration system as a function of the installed capacity. It can be in the US$ 900 to US$ 1100/kW range for 1-5 MW capacity.

Specifying the number of gensets is a matter of concern. Usually, the manufacturer suggests that the minimum operating power can be in 30% to 50% range of full load capacity. Therefore, the number of gensets must be chosen, after having determined the maximum and minimum loads , so that each genset always operates above the minimum value. Sometimes, when the variation is broad, a simulation must be carried on. In this case, when the load becomes smaller, the genset must be turned off, and the electric energy must be purchased from the utility company.

2.5 Partial load operation of gensets

The partial load operation of gensets can be obtained from manufacturer's data, usually at 100%, 75%, 50%, 25% of full load capacity. Linear interpolation between two close values will give in the performance simulation the partial load performance of the genset. When the load is smaller than minimum capacity, say 30%, the genset is turned off and electric energy is purchased from utility company.

2.6 Partial load operation od electric chillers

As before, manufacturer must supply performance data at 100%, 75%, 50%, 25% of full load capacity, so that the linear interpolation scheme gives the partial load performance of the chiller.

2.7 Partial load performance of absorption chillers

Single stage and double stage absorption chillers are mostly used today. Their coefficient of performance at full load are respectively, on the average, 0,65 and 1,05. They are driven by the steam that is produced in a recovery boiler from exhaust gas thermal energy. As before, manufacturer must supply performance data at 100%, 75%, 50%, 25% of full load capacity, so that the linear interpolation scheme gives the partial load performance of the chiller.

Dorgan & allii (1995) compiled the performance curves of different absorption chillers in the market, and generated an average curve to be used in simulations when the data are not available.

A variable X is defined as the ratio between the cooling capacity generated by the chiller under partial load condition and its value at full load. A variable Y is defined as the ratio between the required thermal energy, to be supplied under partial load condition by hot water or steam, and its value at full load. Several curves are then fitted for different cooling water temperatures, such as 13 ^{o}C, 18 ^{o}C, 24 ^{o}C, 29 ^{o}C and 35 ^{o}C.

Eq. (1) was used to fit the single stage chiller performance curves. Table 6 presents the values for the coefficients.

Eq. (2) was used to fit the double stage chiller performance curves. Table 7 presents the values for the coefficients.

$$Y = A.\exp\left(\frac{(\ln(X) - B)^2}{C}\right) \quad (1)$$

$$Y = A.B^X.X^C \quad (2)$$

Table 6 : Single stage performance curve coefficients [To be used in Eq.(1)]

Temperature (^oC)	A	B	C
13	9,7338	1,5466	4,9140
18	10,0028	1,0526	5,9528
24	13,3840	1,5007	4,9767
29	14,5005	1,4425	5,1559
35	17,6766	1,7158	4,9910

Table 7 : Double stage performance curve coefficients [To be used in Eq.(2)]

Temperature (^oC)	A	B	C
13	1,9900	1,0074	0,6101
18	2,1751	1,0068	0,6370
24	2,9036	1,0077	0,5784
29	3,5490	1,0072	0,5683

3. Cogeneration system performance simulation

The performance simulation starts with the knowledge of the thermal and electric load profile.

3.1 Genset operation simulation

At every 15 minutes,

- Compare electric load with genset full load capacity.
  - If the genset capacity is smaller than electric load, it operates at full load. Calculate the fuel consumption at full load.
  - If the genset capacity is larger than electric load, it operates at partial load. Calculate the fuel consumption at partial load.
  - If the electric load is smaller than the minimum operating value, the genset will be turned off. The utility company will supply electric energy.
  - If the genset capacity is smaller than load, the utility company will supply the difference.
- Store genset fuel consumption and electric energy purchased from utility company, and their cost.
- Calculate the thermal energy available in the exhaust gases. Use as exit temperature from the recovery boiler 120 ^oC, if the fuel is natural gas; 180 ^oC - 200 ^oC, for diesel.
- Compare the thermal profile with the available thermal energy
- If the available thermal energy is larger than the thermal profile, discard off the difference
- If the available thermal energy is larger than the thermal profile, and the chiller full load capacity is smaller than thermal profile, it operates at full load. There is no fuel consumption.
  - The difference will be supplied by an electric chiller, purchasing electric energy from the utility company, or by a direct fire absorption chiller, at no fuel consumption. Calculate electric energy consumption.
- If the available thermal energy is larger than the thermal profile, and the full load capacity is larger than thermal profile, the chiller operates at partial load. There is no fuel consumption.
- If the available thermal energy is smaller than the thermal profile, and the chiller full load capacity is smaller than available thermal energy, it operates at full load. There is no fuel consumption.
  - The difference will be supplied by an electric chiller, purchasing electric energy from the utility company, or by a direct fire absorption chiller, at no fuel consumption. Calculate electric energy consumption.
- If the available thermal energy is smaller than the thermal profile, the difference to thermal profile will be supplied by an electric chiller, purchasing electric energy from the utility company, or by a direct fire absorption chiller. Calculate electric energy consumption or fuel consumption.
- If the available thermal energy is smaller than the thermal profile, and the chiller full load capacity is larger than available thermal energy, it operates at partial load. There is no fuel consumption. Discard off excess available thermal energy.

- Store fuel and electric energy consumption, and cost

Repeat all the above procedure for the desired period, calculating operational cost , including fuel and electric energy. Economic parameters can be calculated using the investment to be made in equipment and installation.

4. Validation of the methodology for stablishing the electric load profile

PUC-Rio bought two 1500 kVA diesel gensets, summing up 3000 kVA. A data acquisition system has been measuring every 15 minutes electric energy purchase from the utility company, from October 2001 to September 2002. PUC-Rio gets energy in 13,8 kV, and is classified as A4 Blue tariff. The simulation that follows has two objectives, (a) Validate the methodology proposed in this paper to extrapolate the electric load profile from one month to the whole year, (b) Calculate the cost benefit in using diesel gensets operating at peak periods.

As a baseline, a simulation was carried using available data every 15 minutes. True equipment costs, tariffs and electric energy loads were used. Performance under partial load was obtained from Perkins (2001).

The genset is supposed to operate at peak periods, in parallel with the utility company LIGHT. Sometimes, the profile is smaller than the genset capacity. In this case some energy is purchased from LIGHT. Table 8 presents the results in yearly basis, comparing baseline case (data every 15 minutes) with the proposed methodology (extrapolation).

Table 8 : Performance comparison between methodologies for diesel genset operating at peak periods.

ITEM	Unit	Diesel Genset at Peak Periods		
		Baseline	Methodology	Difference
Consumed EE from LIGHT, off peak	kWh/year	8054942	8033968	20974
Consumed EE from LIGHT, peak	kWh/year	1408	8245	-6837
Purchased EE from LIGHT	R$/year	1516394,00	1533137,00	-16743,00
Diesel Genset EE, off peak	kWh/year	0	0	0
Diesel Genset EE, peak	kWh/year	1125269	922541	202728
Diesel consumption	l/year	292699	240116	52583
Diesel cost	R$/year	380508,00	312150,00	68358,00
Maintenance cost	R$/year	67516,00	55352,00	12164,00
Total operating cost	R$/year	1964419,00	1900639,00	63780,00
Energy cost	R$/kWh	0,214	0,212	0,002

Table 9 presents the results of the economic analysis

Table 9 : Results of the economic analysis

ITEM	Unit	Diesel Genset at Peak Periods	
		Baseline	Methodology
Genset Cost	R$	2265120,00	2265120,00
Lyfe cycle	years	15	15
Operating cost, Utility only	R$/year	2870723,00	2870723,00
Operating cost, Diesel Genset, peak	R$/year	1964419,00	1900639,00
Savings	R$/year	906305,00	970084,00
Payback	years	2,5	2,3
Internal Rate of Return (IRR)	% a.a.	40	43

The present methodology, that extrapolates the load profile, obtained from the utility company for one month, every 15 minutes, to the whole year, multiplying the profile by the ratio between the energy consumption for one month and for the reference month, tends to slightly underpredict the paybak, and to overpredict the IRR. However, the differences are less than 8%. Savings are predicted to within less than 7%. Operating cost, to less than 3%.

These numbers validate the methodology, because they are perfectly acceptable in an economic basis, although wrongly predicting the purchased energy from LIGHT, peak load, for being a small value, according to Table 8.

5. Conclusions

This paper details and proposes a methodology for evaluating the cost benefit of using cogeneration in place of the energy supplied by the utility company. A methodology for estimating the thermal profile is presented and detailed. A methodology for estimating the electric profile is presented and validated by examining a supply of electric energy by diesel gensets at peak periods, and comparing several parameters.

6. Aknowledgement

The authors are indebted to Daniel C.L.Mendes for having developed a software for simulating the technical and economic parameters. The authors are also indebted to LIGHT for having partially supported this research.

7. References

ANEEL, 2002, “Resolução nº 613”, ANEEL
ASHRAE Handbook , 2000, “HVAC Systems and Equipment”, ASHRAE, USA
Dorgan,C.B.,Leight,S.P.,Dorgan,C.E., 1995,”Application Guide for Absorption Cooling/Refrigeration Using Recovered Heat”, ASHRAE
Orlando, J.A.,1996, ”Cogeneration Design Guide”, ASHRAE
Perkins, 2001, “Technical data, 4000 series, Publication nº TSL 4210”, Perkins