EXERGY DIAGNOSIS OF THERMAL AND ELECTRIC SYSTEMS - STUDY OF THE CASE IN AN UNIVERSITY HOSPITAL

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Abstract. *The performance of thermal and electric systems commonly is evaluated through the Energy Analysis. In the electric power section, Energy Diagnosis were disseminated for the energy conservation in the facilities. These diagnosis just base on the First Law of the Thermodynamics, and they don't consider the inherent wastes to the transformations of energy neither the possibility to use more appropriate inputs and processes to the consumers' needs. In this work a methodology is presented for the Exergy Diagnosis of energy systems, based on the Exergy Analysis or of Second Law, in substitution to the isolated energy analysis. Exergy Diagnosis's objective is the rationalization of the use of available energy inputs for the accomplishment of the processes that involve thermal and electric energies, with the higher efficiency and economy of resources, insured your technical and economical viability. The Exergy Diagnosis is divided in the stages of rising, analysis and proposition of optimization measures. For your validation, this methodology is applied into typical energy consumer of the Tertiary Section, the University Hospital Lauro Wanderle, of the Federal University of Paraíba, for which a thermal and electric energy cogeneration system is proposed, using natural gas, as optimization measure in long period, for the comparison among the savings of resources obtained starting from the two types of diagnosis.*

Keywords: *Exergy, Energy, Exergy Analysis, Exergy Diagnosis, Cogeneration.*

1. INTRODUCTION

The intensification of energy consumption has turning necessary a deeper evaluation of energy inputs use, due to the possible exhaustion of no-renewable sources and to the environmental impacts caused by extraction, improvement and use processes.

In Brazil, several linked segments to the energy section have been adding efforts to reach the self-sufficiency of the country, to diversify the Brazilian energy head office and combat the waste of energy for increase of the efficiency. In the Energy Section, optimization measures of the consumption are taken starting from the First Law of the Thermodynamics, seeking the rationalization of final use of inputs for the energy conservation, as it's foreseen in Government's Plans destined to this Section.

In agreement with the Second Law of the Thermodynamics, these measured can not foresee the energy rationalization, because do not consider the quality associated to several energy forms. The Energy Analysis or Analisis of First Law should be complemented by the analysis of irreversibilities and the energy degradation along the processes, in other words, by the analysis based on the Second Law, called Exergy Analisis.

Usually, the actions to turn the facilities more efficient, mainly of electric power, are done starting from the Energy Diagnosis, where is lifted up the wastes points and is made a forecast of electric power consumption to turning them more efficient and less costly. However, these diagnosis equipped the energy readiness of the electricity to those in other ways of energy. This work has as objective presents a methodology for evaluation of energy plants (electric and thermal) based on the Second Law of the Thermodynamics, analyzing the irreversibility and wastes, and the appropriate use of inputs, for the energy and economical rationalization. To validate the developed methodology the case study it is accomplished at a university hospital.

2. ANALISIS OF ENERGY PLANTS

The consumption of natural resources has been reaching higher levels, reducing their supplies and increasing the environmental pollution. A safe provision of energy resources is usually necessary, but not enough for the society development, once it is only insured the development if there is commitment with its sustainability. According to Dincer and Rosen (2004), maintainable development can be defined as that which finds the present needs without committing the capacity of the future generations to find their own needs. The rationalization concept should not be confused with energy rationing, rationalize means use energy in an intelligent way, rationally, while rations denotes restrict its use, what does not assure the efficient use of inputs, besides limiting the activities accomplishment.

In Brazil, according to the Brazilian Energy Balance - BEN (BEN 2007), about 47.5% of the energy head office is renewable, while the world average is of 13.2% and only 6.1% in the developed countries. This characteristic results from the great development of hydroelectric energy generating park, since the decade of 50. The remaining 52.5% of the Energy Intern Offer - OIE are coming of no-renewable sources. The energy use rationalization is fundamental to the decrease of the inherent environmental impact of energy inputs processing and application, to avoid the exhaustion of no-renewable sources, optimize costs, increase the productivity and the systems reliability, and to assure the maintainable development.

In this country, the search for energy inputs rationalization was initiate after the two world crises of petroleum, due to brazilian dependence in foreign oil and to the high prices practiced at the international markets. It was necessary a revision of national politics of energy to diversify the Brazilian Energy Head Office. With this, new guidelines were established as the substitution of imported petroleum by national, use of renewable sources, besides the implantation of Government's Plans to promote the energy conservation.

In this context, the Energy Diagnosis appear as tools for turn the facilities more efficient, mainly in what refers to electric energy. These diagnosis were assimilated by Government's Plans driven to Brazilian Energy Section, as the National Program of Electric Energy Conservation – PROCEL. For the public buildings it was implanted by the Program of Optimization of Publics Buildings – EPP, that foresees the application of energy diagnosis for energy conservation in this buildings (PROCEL, 2001).

The diagnosis fixed by EPP are based in energy analysis, and they have as objective the energy conservation. But, in agreement with Second Law, it's known that energy analysis can't provide the true energy conservation because don't consider the quality associated to several energy kinds. It's verified that these diagnosis don't evaluate the nature of the processes, nor count the losses associated to the energy transformations, therefore they compare the energy readiness of the electricity to those in other ways.

Understand for availability the transformation capacity of energy, named of Exergy. Unlike the energy, exergy can be created or destroyed, and its consumption is proportional to the entropy generation due the irreversibilities. As larger the readiness, best is the quality associated to the energy form in subject. Wall (1986) associated the several energy forms with different quality indexes, as it iss shown in the Table 1.

Table 1 - Quality of the Different Types of Energy

QUALITY LEVEL	TYPE OF ENERGY	QUALITY INDEX (% EXERGY)
EXTRA-SUPERIOR	Potencial Energy	100
	Kinetic Energy	100
	Electrical Energy	100
SUPERIOR	Nuclear Energy	100
	Solar Energy	95
	Chemical Energy	95
	Superheated Steam	60
	District Heat	30
INFERIOR	Low Temperate	5

In Thermodynamics are used rations between the energy input and output to find the processes efficiency that involve energy transformation. Efficiencies calculated with base in energy (energy efficiency) can lead to mistaken interpretations because they are based in the Law of the Conservation of Energy.

In some processes (Rosen 2002) the losses of energy can be big in amount, when actually they are not significant in Thermodynamics view due to the low quality or usefulness of the energy that is lost. The efficiency calculated in exergy base is more significant because it identifies as the process deviates of that ideal, what can be considered as the available margin for the project of a more efficient system for the reduction of the losses.

For Torres (1999) the energy analysis does not count the energy quality that is losing and nor where happens the processes irreversibilities, in other words, it does nt identify where and why they appear. For really turn the facilities more efficient, diagnosis should be accomplished based in the Second Law of the Thermodynamics, named Exergy Diagnosis (Dellabianca, 2004) in analogy to the Energy Diagnosis already existents.

The study of a plant should be initiated by the energy analysis following by the exergy analysis, because they complement their meanings and understanding. For practical ends, in the analysis of volumes of control the following hypotheses are considered (Van Wylen, 1994):

(a) The processes happens in Steady State,

(b) The volume of control does not move in relation to a system of coordinates,

(c) The taxes with that heat and work cross the control surface stay constant,
(d) The mass flow and its state in each discreet area of drainage in the control surface do not vary with the time.

For the following analysis they are considered the parameters and variables defined below:

Nomenclarute

$\delta\dot{E}x$	exergy destruction (kW)
$\dot{E}$	energy flow (kW)
ex	specific exergy (kJ/kg)
$\dot{E}x$	exergy flow (kW)
h	specific enthalpy (kJ/kg)
$\dot{H}$	enthalpy flow (kW)
$\dot{m}$	mass flow (kg/s)
$\dot{I}$	irreversibilities (kW)
P	pressure (kPa)
$\dot{Q}$	heat flow (kW)
s	specific entropy (kJ/kg K)
$\dot{S}$	entropy flow (kJ/s K)
t	time (s)
T	temperature (°C ou K)
$\dot{W}$	work flow (kW)
Z	potencial with relationship to the surface of the earth
V	speed with relationship to the coordinates system

Greeks

δ	irreversibility portion
ε	exergy or rational efficiency (%)
η	energy efficiency (%)
ξ	thermodynamic perfection degree (%)

Subscript

0	enviromment conditions (25°C e 101,35kPa)
e	in
g	generated
i	number of
s	out
VC1 at VC4	control volume

2.1. Energy Analysis

Consider a control volume in which happen mass, heat and work interactions, for processes in steady state the First Law of the Thermodynamics is given mathematically by Eq. (1):

$$\dot{Q}_{vc} = \sum_s \dot{m}(h + \frac{V^2}{2} + gZ) - \sum_e \dot{m}(h + \frac{V^2}{2} + gZ) + \dot{W}_e \tag{1}$$

Where the term on the left represents the energy flow in heat form associated to the control volume, the first two on the right side represent the sums of energies associated to the flows that enter and leave the control volume, and the last term represents the work flow involved in the process. The energy efficiency evaluates the ratio among the taken advantage energy and the energy that enters in the system.

$$\eta = \frac{energia\ utilizada}{energia\ fornecida} \tag{2}$$

2.2. Exergy Analysis

The Second Law of the Thermodynamics establishes that the entropy generation range in the control volume corresponds to the irreversibilities happened during the accomplishment of the process, such that:

$$\dot{S}_g = \sum_s \dot{m}.s - \sum_e \dot{m}.s - \sum_i \frac{\dot{Q}_i}{T_i} \geq 0 \tag{3}$$

Where the term on the left represents the entropy generation range during the processes, the first two on the right side represent the entropy flows associated with the mass which enter and leave the control volume, and the last term represents the entropy flow associated with all heat flows involved in the process. In exergy terms, the Second Law can be expressed in the following way:

$$\dot{E}x_Q = \frac{d\,Ex_{VC}}{dt} + \sum_s \dot{m}.ex_s - \sum_e \dot{m}.ex_e + \dot{W} + \delta\dot{E}x \tag{4}$$

The term to the left represents the exergy flow associated to the interactions of heat, the first two on the right represents, respectively, the exergy flows that leave and enter in the control volume, the third term represents the exergy associated to the developed useful work, and the last term on the right represents the range of internal exergy destruction, due to the process irreversibilities.

For Torres (1999), the exergy or rational efficiency is a ratio between the products exergy and exergy input of the process, could be expressed by:

$$\varepsilon = \frac{Ex_{produto}}{Ex_{entrada}} \tag{5}$$

Some plants or components have no expressive usable exits in exergy terms, they are dissipating processes for which is suggested the Thermodynamic Perfection Degree (Szargut et al, 1988), in other words, the quotient among the sum of every exergy in the exit and the sum of the exergy in the entrance, such that:

$$\xi = \frac{\sum_{s} Ex_{saida}}{\sum_{e} Ex_{entrada}} \tag{6}$$

The division of plants in their several sub-systems makes possible the distinction among the intrinsic losses to each sub-systems and the external losses, and identify where happen the largest exergy losses. The irreversibility is a measure of the inefficiency in a real process. As minor is the transformation capacity of the energy supplied in wanted energy, higher will be the irreversibility associated to the process. The total irreversibility of the plant is the sum of each component irreversibility, such that:

$$I_t = \sum_{j} I_j \tag{7}$$

These parameters make possible identify and determine the plant losses magnitude. The exergy analysis quantifies the input transformation potential, and could be used to evaluate which presents better efficiency for a process. In this way, can be proposed measures to the true optimization and lenses that those based on the energy analysis.

2.3. Stages of the Exergy Diagnosis

In the Exergy Diagnosis are considered all of the available inputs, the nature of transformation processes, their irreversibility and products, while in Energy Diagnosis the energy is just evaluated for the final use. Dellabianca (2004) defines the following stages for Exergy Diagnosis:

(1°) – The Company's Profile,
(2°) – Energy and Exergy auditing of the energy plant,
(3°) – Identification of the facilities and processes,
(4°) – Analysis of the consumption data and operation conditions of the plants,
(5°) – Measures for efficient energy and exergy use,
(6°) – Evaluation of the proposed measures.

3. STUDY OF THE CASE

The study of the case was accomplished at the University Hospital Lauro Wanderley - HULW, of the Federal University of Paraíba - UFPB. This hospital was chosen because it is inserted in EPP context. In this work, will be exposed only the results of energy and exergy analysis of the current installation and the proposition of a cogeneration system for this hospital, as a measure for the efficiency in long period, with the respective savings of energy and capital.

3.1. The Current System

In the energy plant of HULW are used: Electric energy, Fuel Oil Class 1A (OC 1A) and Diesel. The current thermal system uses a boiler with OC 1A that generates steam with pressure of 823,54 kPa with mass flow of 405 kg / h, and it feeds the laundry, the restaurant and the headquarters to sterilization of hospital materials. To the laundry, the steam proceeds with the same pressure with that is generated, while to the restaurant they are made two successive reductions of pressure, one for 196,08 kPa and other for 49,02 kPa, in the sterilization headquarters the pressure is reduced of

823,54 kPa for 196,08 kPa. In the Table 2 the data are presented obtained by the energy ane exergy analysis for the system of steam supply of the Hospital.

Table 2 – Energy and Exergy Analisis of the Current Thermal System

CURRENT THERMAL SYSTEM	
Mass Flow of OC 1A (kg/s)	0,0129
Energy of OC 1A (kW)	517,556
Exergy of OC 1ª (kW)	522,730
Total Mass Flow of Water-Steam (kg/s)	0,1125
Enegy Tranferred for Water-Steam (kW)	298,890
Energy Losses in the Boiler (kW)	281,666
Boiler Irreversibility (kW)	465,044
Pìpe Irreversibility (kW)	32,217
Total Irreversibility of the System (kW)	422,667

The energy of the fuel used in the boiler was determined by its inferior calorific power (PCI), while its specific exergy as calculated following the methodology proposed by Szargut et al (1988). They were considered boiler irreversibility and those due to the pressure reductions in the distribution lines. In the boiler, the losses were calculated from the fuel energy and exergy minus the portions transferred to the steam flow. The largest energy and exergy losses of the thermal system happen in the combustion of OC 1A. The electric power consumption has been increasing considerably, due to the substitution of the steam equipments for equivalent electric, and to growing acquisition of new electro-electronic equipments.

3.2. The Cogeneration System Proposed

For HULW, a cogeneration system of power and heat was proposed. The system configuration is shown in Figure 1.

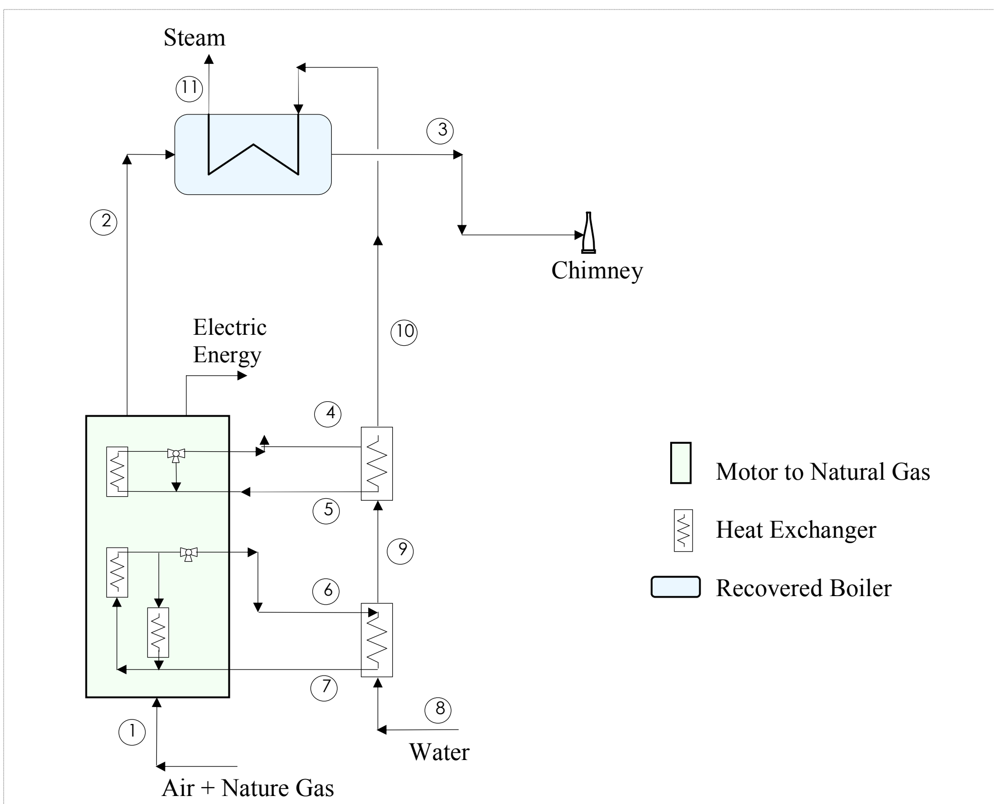

Figure 1. Cogeneration Heat and Power System Proposed

This configuration consists from a motor to natural gas, a recovered boiler and two heat exchangers. This system has capacity to produce 1,404 kWe and the entires steam and heated water demand of the hospital. The choice of the motor is due its short time of departure (10 s), because the steam should be available quickly for the hospital dependences, to the strip of power available (0,05 to 5MW), And to the medium cost of operation and maintenance (between 0,007 and 0,015 U$/kW h). (Santana, 2003)

The energy and exergy analysis of this system were made based in the Mass, Energy and Exergy Balances for the chosen control volumes VC1 at VC4, that are defined as it proceeds: Motor (VC1), Regenerator Boiler (VC2), Low Temperature (VC3) and High Temperature (VC4) Heat Exchangers, for which the points 1 at 11 in the Figure 1 refer to in and out flows.

In the motor is made the natural gas combustion, starting from its mixture with air, transferring the energy fuel for the gasses that work the electric power generator. Them, the exhaustion gasses energy is used in steam production. The water heat of the motor cooling system is taken advantage for the heating of water that can be used in the several activities in the hospital. For the motor, the natural gas energy is determined in a similar way to that was done for OC 1A, being considered its PCI. The same is made to calculate its exergy, with appropriate correction of its PCI.

For the exhaustion gasses, the energy is determined starting from the specific heat at constant pressure, of each chemical component obtained in the natural gas burning, and their respective mass fractions (Santana, 2003). The exergy of these gasses is determined being considered behavior of perfect gas and formation enthalpy for temperature pattern (278 K). In the Table 3 the thermodynamic properties of the cogeneration system fluids are presented.

Table 3 - Thermodynamic Parameters of the Cogeneration Plant Points

POINT	FLOW	$\dot{m}$ (kg/s)	P (kPa)	T (°C)	h (kJ/kg)	s (kJ/kg.K)
1	Air + GN	3,186	100,00	25,00	-	-
2	Exhaustion Gasses	3,186	-	347,00	339,20	7,6100
3	Exhaustion Gasses	3,186	-	155,82	136,30	7,2190
4	Water	9,470	-	100,00	419,10	1,3070
5	Water	9,470	-	91,40	382,80	1,2090
6	Water	11,170	-	44,90	188	0,6373
7	Water	11,170	-	40,00	167,5	0,5724
8	Water	1,860	823,54	25,00	105,6	0,3671
9	Water	1,860	823,54	54,55	229,00	0,7617
10	Water	1,860 e 0,250	823,54	98,67	413,9	1,2910
11	Vapor	0,250	823,54	171,6	2770	6,6530

The values calculated for the energy and exergy variations in the control volumes are in the Table 4, where the column Energy means the amount of energy associated to the flows, as well as the column Exergy means the amount of exergy associated to the same flows .

Table 4 - Energy and Exergy Distribution in the Control Volumes

FLOW	ENERGIA (kW)	EXERGIA (kW)
Natural Gas (1)	4.072,35	4.267,82
Eletric Energy	1.404,00	1.404,00
Exhaustion Gasses (2)	1.057,61	350,73
Exhaustion Gasses (2_3)	-664,24	276,08
Water (4_5)	-344,00	67,19
Water (6_7)	-229,00	12,96
Water (8_9)	229,00	-10,79
Watera (9_10)	344,00	-50,53
Mixture of Water and Steam (10_11)	589,03	-189,56

For calculate the Total Energy Efficiency, it was considered the relation among the sum of the energy flows associates to the generated electric power and the states of the steam and hot water produced with the energy contained in natural gas. Similarly, to calculate the Total Exergy Efficiency, it was considered the relation among the sum of the exergy flows associated to the generated electric power and the states of the steam and hot water produced, with the exergy contained in the natural gas. These results are exposed in the Table 5.

Table 5 - Performance Parameters of the Plant Control Volumes

VC	$\dot{I}$ (kW)	η (%)	ε (%)	ξ (%)
VC1	2.432,93	34,47	32,90	43,00
VC2	86,52	88,67	68,66	75,83
VC3	2,17	100,00	83,26	99,60
VC4	16,66	100,00	75,20	94,14
TOTAL	2.538,28	63,01	38,77	-

The largest energy and exergy losses of the system happen in the motor and are due to: the radiation through its surface, to the heat transferred by the cooling systems, and mainly during the internal combustion and in the work of the movable parts of the electric power generator.

It should be observed that there is a great loss of chemical energy of the natural gas components during to combustion reactions, because not all the gas is indeed burned in the motor for the liberation of heat. In other words, part of the natural gas energy leaves of being liberated due to the character non perfect of the reaction.

The cogeneration system considered using motor for the natural gas firing foresees that the steam demands and electric power are supplied. In this article the authors just made a comparison among the current cost of the electric energy and of the OC 1A consumed now at the hospital with that which would be due to the regular operation of the system.

The costs with the fuel oil purchase OC 1A, on average R$ 22737.00 monthly, they should be rearrange for the purchase of the natural gas. The monthly consumption of foreseen natural gas, for a daily operation of cogeneration system same to the original period of the boiler (of the 6:00 to the 19:00 in the useful days and from 6:00 to 12:00, in the end-of-week) would be of 22792 kg weekly.

To calculate the monthly natural gas costs is necessary to convert the consumption in kg for m^3 that is used by the Gas Company of Paraiba – PBGÁS. For this conversion were considered the thermodynamic properties of the Methane, that it is the main hydrocarbon of natural gas, and gas at 298 K and 101 kPa, that are the thermodynamic parameters of the fuel distributed by PBGÁS.

The natural gas specific volume for these conditions is 1.501 m3/kg. With this value, is considered that its consumption is 34210.79 m3 during a week. In agreement with the consumption strips established by PBGÁS, the dear consumption can be framed for HULW in the strip of 1.00 the 35000 m3/week, whose tariff is R$ 1.009 / m3. This way, the cost foreseen with natural gas to supply the demand of the system for the cogeneration system proposed is R$ 138674.25. In comparison with the current costs with fuel oil 1A (R$ 22737.00), added at the costs for the electric power consumption (average of R $ 170000.00 monthly), the costs foreseen for the proposed system represent an economy of R$ 54662.25.

It should be observed that the amount of electric power cogenerated can supply other areas of the campus, tends in view that there is spare generation of electricity regarding the demand of the own hospital. Like this, the cogeneration would represent a reduction in the invoice of electric power for the Campus I of UFPB very largest than calculated.

4. CONCLUSION

The analysis based on the 2nd Law, or Exergy Analisis, is a powerful tool for project, study and optimization of energy systems, being applicable in decisions of investments, in the comparison of implementation techniques and operational conditions, in the use of alternative sources, in the expansion of a energy system, etc. The proposition of the Exergy Diagnosis in front of the Energy Diagnosis has as objective increases the reliability of the efficiency of plants that involves energy, because the analisis based on the energy conservation can take to wrong decisions, masking the true wastes and irreversibilities in real process.

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7. RESPONSABILITY NOTICE

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