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WHY HOSPITALS ARE PRIME CANDIDATES FOR CHP SYSTEMS

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ABSTRACT
In the present article the authors make an effort to explain why hospitals are prime candidates for CHP systems. Furthermore based to the fact that CHP is a proven technology, are referring analytically to the benefits of cogeneration in the health care facilities giving also a case study.

KEY WORDS
Cogeneration, Electricity, Thermal energy, Hospital, Energy Saving.

1. Introduction

Hospitals are generally great consumers of energy, both electrical and thermal [1,2]. The energy consumption intended for the coverage of thermal requirements, mainly consist of partial loads as follows [1,2]: heating, sanitary hot water, sterilization, kitchen thermal load and laundry thermal load. The energy consumption intended for the coverage of electrical requirements mainly consists of partial electric loads as follows [1,2]: lighting, cooling, motoring in general, stationary and portable medical equipment, electric load for kitchen and electric load for laundry.
A lower consumption of this energy will contribute not only to a reduction in the running costs of the hospital, but also in the reduction of pollutant emissions that contribute to the greenhouse effect and a less dependence of the hospital on the external power supply.

2. What is Combined Heat and Power (CHP)

The usual (conventional) way to cover the needs in electricity and heat is to purchase electricity from the local grid and generate heat by burning fuel in a boiler. However, a considerable decrease in total fuel consumption is achieved if cogeneration (known also as combined heat and power, CHP) is applied.
"Cogeneration is the combined production of electrical (or mechanical) and useful thermal energy from the same primary energy source" [3].

The mechanical energy produced can also be used to drive auxiliary equipment such as compressors and pumps. Regarding the thermal energy produced, it can be used either for heating or for cooling. Cooling is effected by an absorption unit, which can operate through hot water, steam or hot gases. During the operation of a conventional power plant, large quantities of heat are rejected in the atmosphere either through the cooling circuits (steam condensers, cooling towers etc.) or with the exhaust gases. Most of this heat can be recovered and used to cover thermal needs, thus increasing the efficiency from 30-50% of a power plant, to 80-90% of a cogeneration system [3]. A comparison between cogeneration and the separate production of electricity and heat from the point of view of efficiency is given in Figure 1 [3] based on typical values of efficiencies.

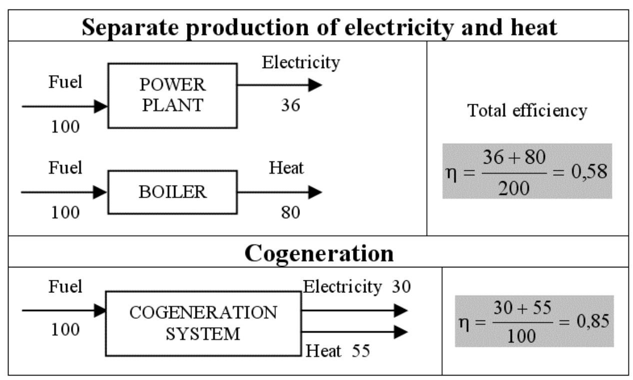

Figure 1: Efficiency comparison between cogeneration and separate production of electricity and heat. (Numbers below arrows represent units of energy in typical values) [3].

All buildings that are designed for people, need energy-heat to provide warmth and hot water, and electrical power to provide light and other services. Hospital buildings normally drive their heat and electrical power separately, heat from boilers (burning gas, oil) and electricity via the national grid from power stations which burn gas, oil and coal. This approach leads to two sets of losses from the power station generator and from the local boiler. A CHP unit eliminates some of the losses by burning fuel to generate electricity and at the same time using the "waste" heat to provide warmth and hot water for use in the hospital [4].
A more precise definition applicable in healthcare facilities is given to bibliography [5]. "CHP is an integrated system located at or near a building or facility

which provides at least a portion of the building's electric generation equipment to provide space heating, space cooling, domestic hot water, dehumidification, sterilization and/or process heat".

3. CHP technologies

According to the same bibliography [5] the "reliable" CHP technologies employed in the system include

- Electric generation equipment
    - Gas Turbines
    - Microturbines
    - Reciprocating engines
    - Steam turbines
- Heat recovery systems
    - Steam and hot water Exhaust gases
- Thermal activated Technology
    - Absorption chillers
    - Desiccant dehumidification

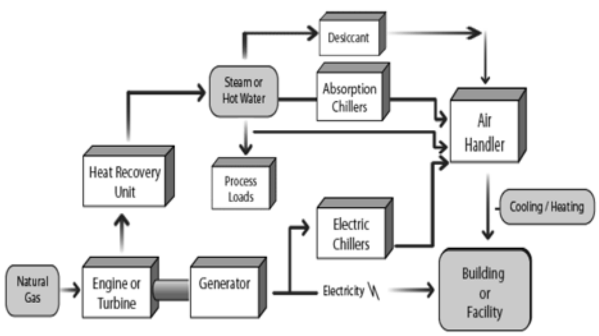

Figure 2: A typical CHP system for a Hospital Facility [6].

Figure 2 shows what a typical CHP system for a Hospital Facility includes [6].
Combined heat and power (CHP) uses either a gas turbine, a steam turbine or a gas-fired or oil-fired engine to drive an electricity generator, and makes practical use of the heat which is an inevitable by-product. This heat can be used for making process steam, space heating, domestic hot water and now, increasingly, for cooling using absorption chillers.

4. Why Hospitals are prime candidates for CHP systems?

The hospital is in itself the equivalent of a small town, where up to several thousands people medical, administrative and technical staff, patients and resident personnel work and live. Indeed all energy uses and generally all forms of available energy are employed to meet the very large demands of a hospital. Heating ranks first among energy expenditures, mainly in northern European countries, closely followed by electricity uses which have been increasing very rapidly over the last twenty years, and then by hot water production, laundry and meal services. Electricity is almost always used for air-conditioning and treatment, lighting and medical equipment.
Compared to other types of buildings in the services sector, hospitals and clinics have significantly higher energy consumption in relation to volume and surface area [7]. There are two reasons for this, partially justifiable, i.e.:

- around-the-clock operations, all year long
- proper temperatures for patients comfort

Hospitals are potential candidates for CHP under the following conditions [5]

- High thermal and electrical loads that occur coincidentally
- Sufficient "spark spread" (difference in price per site kWh between gas and electricity)
- Long operating hours
- Central heating and cooling systems in place
- Minimal electric distribution connections
- Special electrical, cooling and/or heating needs.

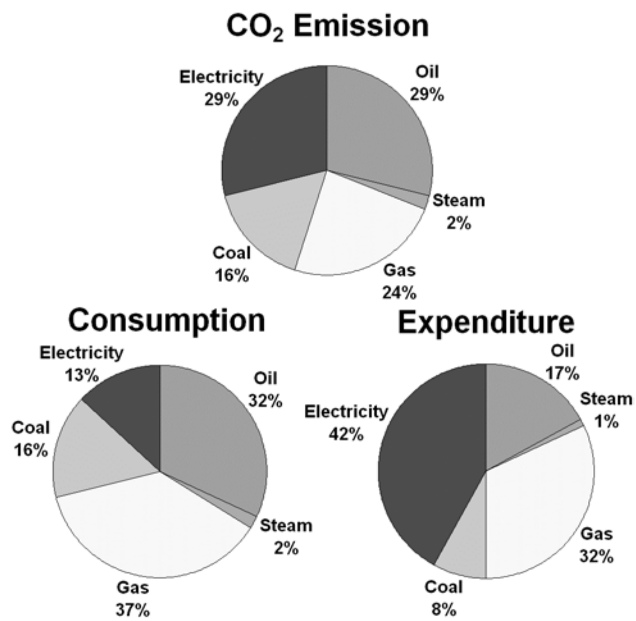

Figure 3: Electricity consumption, CO_2 emission and cost in the NHS hospitals in the U.K. in 1992 [9].

Additionally can provide to the hospital [8]

- High Power Reliability
- High Power Quality

which are important to the hospital since eliminates black outs, brown-outs, curtailments and surges. Providing quality health care and safety for patients is of greatest importance to health care providers. Lives depend on constant operation of equipment as well as a comfortable living environment, therefore power failures can not be tolerated.
Combined heat and power technologies utilize the waste heat generated from on-site electricity production to provide heating. The use of CHP for supplying part of the energy and heating requirements of a new building is now an established good practice [9]. Electricity supply is the most expensive source of energy for hospital use,

representing around 42% of energy expenditure but only 13% of consumption [9], as illustrated in Fig.3.
In 1992 the National Hospital Service (NHS) in U.K. spent over of £300 million on energy, £125 million was electricity [10] and the annual rising rate was aprox. 7% [9].
A CHP system will not reduce total energy demand, but by generating a portion of the electrical requirements, whilst generating heat for the site, the total amount of fuel and costs involved are reduced considerably [4].
In USA the total energy consumption by the healthcare industry in 1999 was 258 trillion BTU, which was approximately 13 percent of the total U.S. commercial consumption [5]. Hospitals in the U.S. spend an average of $1,67 on electricity and 48 cents on natural gas per square foot annually. In a typical hospital, lighting, heating and hot water represent between 61 and 79 percent of total energy use depending on climate [11].
Furthermore hospital power consumption is more constant than other commercial loads [5].

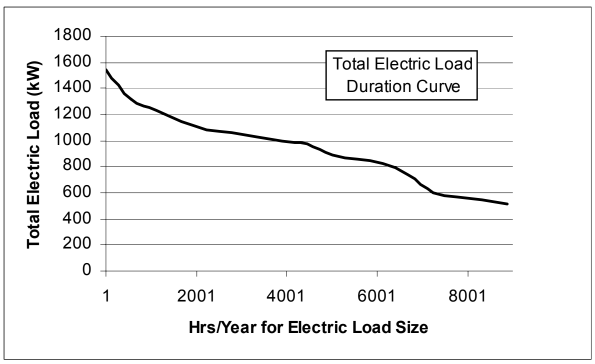

Figure 4: Hrs/Year for Electric Load in a Hospital 8500m^2.

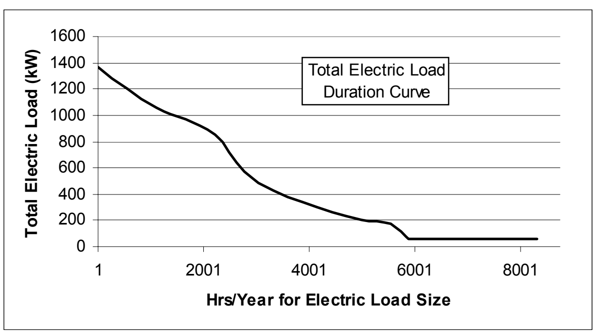

Figure 5: Hrs/Year for Electric Load in an Office Building 8500m^2.

Figure 4 shows the total load duration curve in a hospital of 8500m^2 while Figure 5 the total electric load duration curve in an office building with the same floor area [6].
Figure 6 shows a typical thermal load curve in a hospital. A single CHP unit with a maximum thermal output of 290kW is illustrated, which would work for around 4600 hours per year at full load (covering approximately 40% of total thermal load). Reciprocating engines will not run at less than 50% load with an acceptable efficiency, and with gas turbine the limit is more likely to be 70%. With this limitation the CHP unit in this example would operate for a further 1859 hours at partial load (covering approximately 49% of the total thermal load) and the remaining heat demand would be provided by firing boilers in the conventional manner [12].

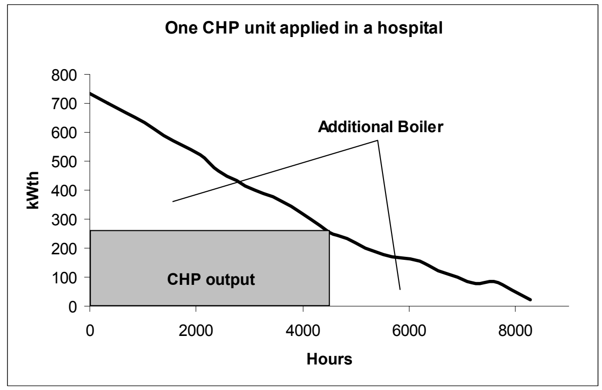

Figure 6: Typical Thermal Load curve in a hospital [4].

5. CHP is a proven technology

CHP is a proven technology worldwide. This is the reason the European Parliament and the Council of the European Union, after considering the following:

- Promotion of high - efficiency cogeneration, based on a useful heat demand, is a Community priority given the potential benefits of cogeneration with regard to saving primary energy, avoiding network losses and reducing emissions, in particular of greenhouse gases. In addition, efficient use of energy by cogeneration can also contribute positively to the security of energy supply and to the competitive situation of the European Union and its Member States. It is therefore necessary to take measures to ensure that the potential is better exploited within the framework of the internal energy market.
- In its Resolution of 15 November 2001 on the Green Paper [13,14], the European Parliament called for incentives to encourage a shift towards efficient energy production plants, including combined heat and power.
- The increased use of cogeneration geared towards making primary energy savings could constitute an important part of the package of measures needed to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change, and of any policy package to meet further commitments. The Commission identified promotion of cogeneration as one of the measures needed to reduce the greenhouse gas emissions from energy sector and announced its intention to present a proposal for a Directive on the promotion of cogeneration in 2002.
- Number of other previous resolutions [15,20] and directives [21], *issued the directive 2004/8/EC* [22].

The purpose of this Directive is to increase energy efficiency and improve security of supply by creating a framework for promotion and development of high efficiency cogeneration of heat and power based on useful heat demand and primary energy savings in the internal

energy market, taking into account the specific national circumstances especially concerning climatic and economic conditions.
In the United States also *the National Energy Plan released in 2003*, states in section 3-5. “A family of technologies known as combined heat and power (CHP) can achieve efficiencies of 80% or more. In addition to environmental benefits, cogeneration projects offer efficiency and cost savings in a variety of settings, including industrial boilers, energy systems and small, building applications. Cogeneration is also one of a group of clean, highly reliable, distributed energy technologies, that reduce the amount of electricity lost in transmission, while eliminating the need to construct expensive power lines to transmit power from large central power plants”.
The use of CHP in hospitals is not new [12]. A survey undertaken early in 1991 identified that over 92 small-scale systems of less than 500kWe (installed electrical capacity) were already operational at 74 hospital sites throughout the UK, representing a combined electrical output of 8,25MWe. In addition there were growing number of large-scale CHP schemes, with at least 15MWe of combined electrical output already operational, and further schemes were being designed and installed. A further 25MWe of electrical capacity (over six separate sites) was in the final stages of detailed design and specification. In USA in 2005 there were more than 200 CHP installations in hospitals with a size range from 100kWe up to 50MWe representing a combined electrical output of aprox. 4,7MWe [23].

6. Benefits of CHP

Choosing CHP could reduce energy costs, increase the security of supply and at the same time improve hospital’s environmental performance. Figure 7 summarizes the benefits of CHP [24].

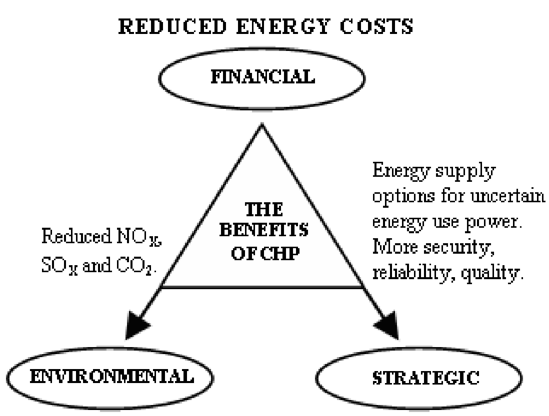

Figure 7: Summary of the benefits of CHP [24].

6.1 Benefits to the patients

The security of electrical supply is of the utmost importance in hospitals, since in local and regional disasters, patient transfers and evacuations can be deadly. Furthermore loss of power puts patients currently undergoing critical procedures at risk. Additionally “brown outs” and “Voltage sags” can shut down sensitive diagnostic equipment and interrupt non-critical procedures. A facility that can remain fully functional can avoid these risks to its patients [23].

6.2 Benefits to the hospitals

The use of fully digital Medical Records, the bar code, Scan Drug delivery etc. requires a more reliable normal power. In addition local generation provides fewer sags and surges and drives to a higher quality normal power. From the other side in the event of a grid failure due to natural, technical or terrorist causes, the hospital will remain in operation when needed most. A CHP facility in a hospital can supply 100% of the hospital needs, not only to cover the life safety requirements. Furthermore CHP can contribute to the sustainable development in the Health sector [23].
On-site power natural gas generators can be used for primary power, base-load power, peak shaving or emergency power. Hospitals can decide when to generate their own power and when to use power from the utility company. A CHP system owned by a capital partner offers initial capital savings to allow to the hospital to redirect its own capital towards its core healthcare mission. Furthermore at the hospital’s option, capital savings can be used to improve the energy efficiency of the hospital itself through demand side energy conservation improvements [23].

6.3 Benefits to the Environment

CHP installations generate electricity and make use of the heat that is wasted in conventional power generation. In addition, nearly all CHP systems currently installed in hospital buildings are fired by natural gas. Consequently, the use of CHP results in:

- reduced production of CO_2
- reduced pollution, for example nitrogen oxides (NO_x) and sulphur oxides (SO_x) which are the principal sources of acid rain.
- reduced particulate matter
- reduced use of finite natural resources

Hospitals have a duty to promote health gain, which involves in the broader sense the conservation and use of sustainable natural resources and to minimize the damage to the environment resulting from their own activities, encouraging others to follow their examples [12].

6.4 Benefits to the public

Much of the energy used today is delivered from non-renewable resources, and its generation inflicts environmental damage both directly and indirectly. The burning of fossil fuels is responsible for the greatest proportion of carbon dioxide (CO_2) produced each year, the principal greenhouse gas which contributes to global warming. CHP improves environmental quality due to more efficient fuel use [12].

6.5 Benefits to the Government

CHP may also benefit the national economy if it results in reduction of the total expenses for imported fuels. Furthermore it may have important social and economical implications in sectors such as business development patterns and the role of policies in energy supply i.e. alternate fuels, Energy Service Companies (ESCO), Third Party Financed (TPF) [23,25].

7. A Case Study

In the frame of this work we considered a Greek hospital in Athens area, of 34000m^2 total floor area and 540 beds. The scenario is the installation of a suitable trigeneration system in order to cover the bigger part of electrical, thermal and cooling requirements of this hospital. As conventional operation we considered the use of boilers burning diesel oil for space heating, production of sanitary hot water as also steam and buying electrical power from the grid.

7.1 Electrical energy consumption

The electrical energy consumption of the hospital mainly consists from lighting, motoring (elevators, motors for the pumps etc.), office equipment (PCs and printers), stationary medical equipment (two sector scanners and one real time scanner), laboratories equipment as also cooling towers and split type air conditioning units.
The monthly electrical demand, (kWh$_e$) and the peak power noticed (kW) based on bills collected for the year 2003 are presented in Table 1.

Month	Electrical energy (kWh)	Maximum Electrical Power (kW)	Utilization Factor
JANUARY	490000	962	68,46
FEBRUARY	398400	958	61,88
MARCH	439200	958	61,62
APRIL	350400	905	53,77
MAY	513600	967	71,38
JUNE	513600	1176	60,65
JULY	542400	1243	58,65
AUGUST	664800	1166	76,6
SEPTEMBER	444000	1274	48,39
OCTOBER	506400	960	73,26
NOVEMBER	417600	890	64,38
DECEMBER	331200	900	49,46
	TOTAL	**MAX VALUE**	**ANNUAL**
	5611600	**1274**	**50,28**

Table 1: Monthly electrical demand (kWh$_e$), peak power (kW) as also utilization factor in a 540 beds hospital.

The hospital is supplied power through two transformers of 1000kVA each from the grid (medium voltage). A new one of 1000kVA also was ready to be installed.
Figure 8 shows the monthly electrical energy demand and peak power for the year 2003 in a 540 beds hospital.

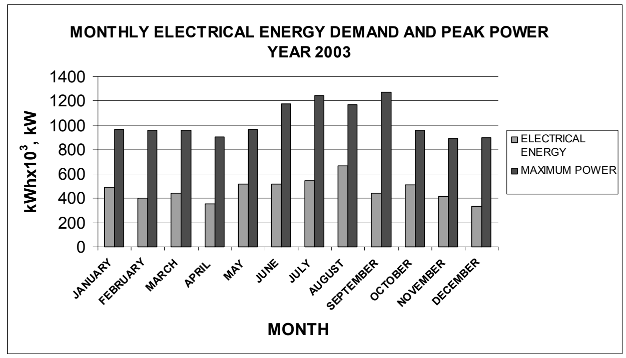

Figure 8: Monthly electrical energy demand and peak power for year 2003 in a 540 beds hospital.

The monthly utilization factor varies from 50% to 77% during a typical year while the yearly one is aprox. 50%. The maximum electrical demand for a year is 5612MWh$_e$ and the peak power (1274kW) noticed in September. Table 1 show that the electrical demand is increasing by 35-40% during summer period due to space cooling (use of electric cooling towers, fan coils and split air-conditioning units). According to collected data for a period of three years the electrical demand is increasing by 12% each year.

7.2 Thermal energy demand

The thermal energy demand of the hospital mainly consists of sanitary hot water through suitable heat exchangers, hot water for space heating and steam for the laundry, the kitchen and the sterilization unit. The thermal energy is fully covered by burning diesel oil.
The monthly fuel consumption in liters (l) and the corresponding thermal demand (kWh$_{th}$) is presented in Table 2 (Diesel oil's Lower Heating Value LHV=10kWh/l).

Month	Fuel Consumption (l)	Thermal Demand (kWh$_{th}$)
JANUARY	172052	1720520
FEBRUARY	183996	1839960
MARCH	163778	1637780
APRIL	125265	1252650
MAY	78936	789360
JUNE	61099	610990
JULY	78323	783230
AUGUST	76323	763230
SEPTEMBER	77750	777500
OCTOBER	96642	966420
NOVEMBER	118274	1182740
DECEMBER	166189	1661890
TOTAL	**1398627**	**13986270**

Table 2: Monthly fuel consumption in (l) and thermal demand (kWh$_{th}$)

The thermal consumption is maximized in winter months in contrary with electrical consumption due to space heating requirements.
Figure 9 shows the monthly fuel demand (kWh_{th}) for year 2003 in a 540 beds hospital.

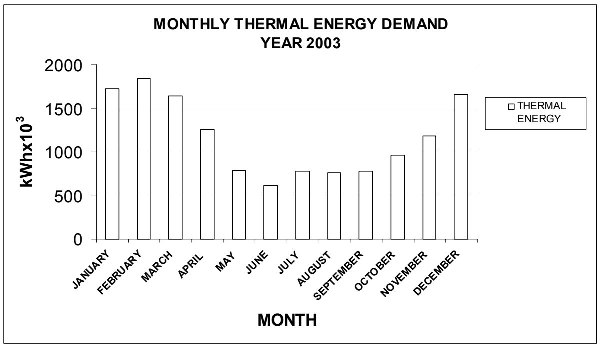

Figure 9: Monthly thermal energy demand (kWh_{th}) for year 2003 in a 540 beds hospital.

7.3 Total energy consumption. Cost of conventional operation

From par.7.1 the total electrical demand for a typical year found to be $5612MWh_e$. The annual cost for power was 422279€ (prices for power of year 2005).
The total annual thermal demand according to par.7.2 found to be $13986MWh_{th}$. The annual cost for the fuel was 609000€ (average price of diesel oil 0,436€/l for 2005). The total annual energy cost according to the conventional operation for all energy demands is 1031279€. The electricity cost is approximately 40% of the total energy cost while covers only 28% of total hospital's energy requirements.

7.4 The application of Trigeneration

Trigeneration implies the simultaneous production of mechanical power (electricity), heat and cooling from a single fuel. The trigeneration system considered for this hospital includes: Two gas engines of $507kW_e$ each, fueled with natural gas, two asynchronous generators , one (or two) heat recovery boiler(s) using exhaust gases for steam production, a double effect absorption cooler of 250RT, which will operate with exhaust gases from gas engines either with steam produced by heat recovery boiler(s), heat exchangers for heat recovery from the cooling cylinders circuit, as well from the lubricating oil circuit. In addition a steam pipe network will connect the exhaust gas heat recovery boiler with the existing network of the hospital in order to cover partially its thermal requirements. Furthermore a water pipe network will connect the heat exchangers with the existing network. A transformer of aprox. 1400-1600kVA must also be installed in order to increase the generators voltage output to 20kV (medium voltage) in order these to be connected with the grid. The project also includes the change of existing burners in dual fuel ones (i.e. these to have the ability to burn natural gas as also diesel oil in case of emergency). Table 3 gives the operational characteristics of CHP system in 540 beds hospital.
Table 4 presents energy and cost data for a CHP system in a 540 beds hospital.
The installation of the new burners will make possible to existing boilers to burn natural gas instead of diesel oil (the natural gas boiler efficiency considered as 0,90 and the lower heating value of natural gas as $10,17kWh/m^3$).
The thermal load not covered by CHP is $13986 - 5060 = 8926\ MWh_{th}$ or $9918MWh_{th}$ of natural gas or $975199Nm^3$ of natural gas or $11208MWh_{HHV}$ (HHV: Higher Heating value $11,4935kWh/m^3$).
The average price of natural gas in 2005 was $33,1€/MWh_{HHV}$, therefore the total cost for thermal requirements not covered by CHP is 371000€.

Description	Unit	Value
Electrical Power of gas engines	kW_e	1014
Nominal electrical efficiencies	%	35
Nominal thermal efficiencies	%	47
Total Nominal efficiency	%	82
CHP annual electrical energy production	MWh_e	6794
CHP annual thermal/cooling energy consumption	MWh_{th}	5060
CHP fuel (natural gas) energy consumption	MW_{LHV}	19411
CHP annual electrical efficiency	%	35
CHP annual thermal efficiency	%	26
CHP annual total efficiency (LHV)	%	61
Nominal thermal power of natural gas consumed	kW	2897
Nominal delivered electric power	kW	1014
Nominal delivered thermal power	kW	1362

Table 3: Operational characteristics of CHP system in 540 beds Hospital.

Description	Unit	Value
CHP electric energy production	kWh	6794000
Hospital's electric demand covered by CHP	kWh	5024296
Lack of electrical energy bought from the grid	kWh	587304
Excess of electrical energy sold to the grid	kWh	1796704
Cost of electrical energy bought after CHP installation	Euro	44200
Income from selling electrical energy excess	Euro	78000
Fuel savings from CHP, covering thermal loads as percentage of total annual fuel consumption, for thermal loads	%	5060/19411 = 26
Annual fuel energy used by CHP	kWh_{LHV}	19411000
CHP Annual fuel consumption	Nm^3	1908653
Total cost of natural gas for CHP	Euro	559000

Table 4: Energy and cost data for a CHP system in a 540 beds hospital.

The energy cost according to the conventional mode found (par.7.3) 1031279€. If we assume maintenance cost of 4,5€/MWh the annual cost will be 30573€. Thus the energy cost with CHP will be:

(44200 – 78000 + 559000 + 371000 + 30573) = 926773€. Finally the total earnings from CHP installation is (1031279 – 926773 = 104506 €). (i.e. 10% as percentage of the cost of conventional operation.

The CHP installation drives to considerably smaller vapors emission. Specifically the reduced production for CO_2 is aprox. 46%, for nitrogen oxides (NO_x) is aprox. 68%, for CO aprox. 72%, while for sulphur oxides (SO_x) almost 100%, as also for the particulates matter.

8. Conclusion

In this work an effort is made to prove that CHP systems can offer to hospitals serious savings in operation and capital helping to protect the environment and the public health.

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