Analysis of Performance of CCHP Systems for Large Hospitals

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Abstract—**Hospitals are large public buildings that have a significant impact on the environment because they use large amounts of energy and water and produce large amounts of waste. For these reasons, hospitals are natural candidates for sustainable design. The design of heating ventilation and air conditioning (HVAC) plants for large hospitals must aim to some top priority objectives: improve their energy efficiency, forecast the use of clean innovative technologies of self production of energy, reduce both the operating costs of HVAC plants and polluting impacts on environment, guarantee the continuity of energy supply from every case of critical states and black-out of electrical energy or natural gas. In the context of cooling/heating efficient energy, we illustrate the benefits obtained by means the use of a system of "Combined Cooling Heating and Power" for the San Marco Catania's Hospital. This paper shows in what way is guaranteed the continuity of energy supply for any possible critical state, the economic gain through the auto-production of energy that reduces of about 1.000 M€ the operating cost of HVAC plants, the environmental benefits due to the reduction of about 25 Mtons of carbon dioxide equivalent.**

Keywords-HVAC systems; saving energy; CCHP; greenhouse emissions.

I. INTRODUCTION

Hospitals are large public buildings that have a significant impact on the environment and economy of the surrounding community. They use large amounts of energy and water and produce large amounts of wastes so they are natural candidates for sustainable design. In today's expanding energy hungry world, sustainability is no longer an option, it has become the design standard for design professionals.

The Combined Cooling Heat and Power (CCHP) plant provide cooling alongside heat and power from the same energy source into a 'tri-generation' scheme.

CCHP plants have a higher efficiency than systems that producing only heating or power because CCHP system uses waste heat from electricity generation to produce steam for heating and cooling. Fig. 1 shows a typical scheme of CCHP plant.

The performance of CCHP systems has been studied before [1][2][3]. The CCHP plants are particularly useful for buildings, like hospitals, that have large amounts of air conditioning needs.

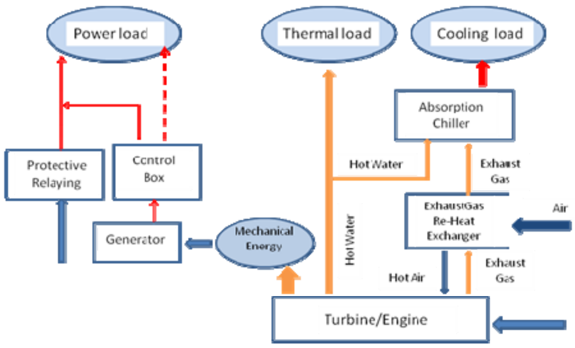

Figure 1. Typical CCHP system

Because CCHP uses waste heat to produce thermal energy for heating and cooling, hospitals equipped with CCHP systems are more energetically efficient.

Hospitals are ideal candidates for CCHP systems because they work 365 days for year and require round the clock energy. In the world, the number of hospitals using CCHP systems has grown steadily in recent years. Combined systems enable hospitals to reduce energy costs, increase reliability on energy availability and improve environmental performance.

With less fuel consumed, greenhouse gases (GHG) and air pollutants (nitrogen oxides and sulfur dioxides) are reduced [4]. Resources saved could be redirected to improve patient care [5]. Moreover, hospitals must perform critical, life-saving functions even when a widespread disaster interrupts their supply of natural gas and electricity from the utility grid. CCHP systems can be designed to maintain critical life-support systems, operate independently of the grid during emergencies and be capable of black start (the ability to come online without relying on external energy sources). Blackout of electrical national grid or further possible negative happenings (terrorist outrages, oil crisis caused by war events in oil producing countries, and so on) directs people efforts to have more sources of energy supplying and reach the maximum possible of energetic independence of the hospital. Because of they are already up and running, CCHP systems can offer a seamless, reliable power alternative than traditional emergency generators.

The CCHP systems, however, are not automatically configured for backup capability; hospitals must ensure that

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the systems have automatic transfer capability and that the energy output can be matched with energy demand.

The CCHP systems are not always advantageous for all typologies of hospitals: their cost-effectiveness needs to be evaluated on a case by case basis. In determining a CCHP system's viability, there are several important considerations: interconnection agreements, site issues, and permits all should be discussed with the partnering utility. Local and national incentives including direct financial grants, tax incentives, and low interest loans should be determined. The type of driving unit and cooling device distinguish different kinds of CCHP systems. A CCHP driving unit module can be a steam turbine, a gas turbine, a reciprocating engine, or a fuel cell. A turbo or absorption chiller generally produces the cooling energy from a CCHP system, the choice depends on the required output power and operating regime [6].

Designers must choose equipment that best fits the hospital's thermal and electrical loads and power quality requirements. The CCHP systems often can be installed for less cost upfront than renewable energy options such as photovoltaic systems of a similar scale. When matched to suitable loads, some CCHP systems can provide a simple payback in the five to ten year range, depending on system size and energy costs [7].

This work provides a quantitatively analysis of the significant benefits that can be brought by the CCHP systems.

The paper has the following structure: Section II describes the main characteristics of the building complex; Section III reports the main energy flow and the financial advantages obtainable by the CCHP system. We conclude in Section IV.

II. THE SAN MARCO HOSPITAL

The "San Marco Hospital and Orthopedically Institute of Excellence" is located in the metropolitan area of Catania city, close to many facilities as like as airport, harbor and link roads with Sicilian motorway as Figure 2. It takes up an area of about 230.500 m^2, the buildings of whole complex cover a surface about 28.500 m^2 and the total buildings cubature is about 405.000 m^3.

Figure 2. San Marco Hospital and Orthopaedical Institute of Excellence with Building Area in evidence

Figures 3 and 4 show some views of hospital's buildings. San Marco Hospital is an ideal candidate for a CCHP system because it operates 365 days for year and requires round the clock energy. A combined system could enable the hospital to reduce energy costs, improve environmental performance, and increase energy reliability. During the Italy blackout of electrical national network of 28 September 2003, many hospitals had failures in their backup power generators. Blackout of electrical national grid and further possible negative happenings (terrorist outrages, oil crisis caused by war time events in oil producing countries, anomalies in national electrical distribution system, and so on) directs people efforts towards design of HVAC plants in such a way both to render energy supplying not dependent by an unique source and to reach the maximum possible as regard to energetic independence of the hospital.

Figure 3. San Marco Hospital and Orthopaedical Institute of Excellence

Figure 4. San Marco Hospital and Orthopaedical Institute of Excellence

A. *Hospital's energy needs*

The Hospital's thermal needs (cooling, space heating, domestic hot water, steam, and ventilation) have been calculated using the MC4 software [8], which is a multi-use software program that calculates load and energy efficiency for any type of building. The electrical needs (lighting, large medical equipment, distributed medical equipment & plug loads) have been calculated in function of the electric power of all the utilities operating simultaneously.

The calculated power peak loads are shown in Table I.

TABLE I. DATA OF PEAK DEMAND

Thermal power (Winter)	**kW**
Domestic Hot Water	1.425
Space Heating and Ventilation	5.607
Hot Water Separated Circuits	1.415
Various Utilities	1.650
General Amount	*10.097*
Steam needs (Summer)	**kg/h**
Domestic Hot Water	2.052
Absorption Chillers	18.400
Ventilation	1.346
Various Utilities	2.376
General Amount	*24.174*
Electrical power (Summer)	**kW**
Ventilation	815
Indoor Lighting	350
Outdoor Lighting	60
Electro-medical Equipments	1.200
Chillers	670
Operating Theatres	560
Various Utilities	936
General Amount	*3.366*
Cooling power (Summer)	**kW**
Space Cooling, Ventilation	10.392
Cold Water Separated Circuits	679
General Amount	*11.071*

B. *Architecture of the energy system*

Hospitals have to be able to generate their own base load power, in conjunction with or as a backup for the main electricity in the event of an unexpected loss of electricity and/or emergency. System energy supply has been designed to operate independently of the grid during emergencies, and to be able to come online without relying on external energy sources maintaining the critical life support systems. For these reasons, designers have foreseen to utilize three distinct energetic sources:

- Natural gas, to feed the gas turbine during normal service and, in case of emergency or for request of peak loads , three steam generators
- Electric energy coming from national network during periods of maintenance or out of order of turbine.
- Gas oil to feed in emergency (lack of natural gas) three steam generators.

The architecture of the energy system feeding to the various machines and equipments of HVAC plant is shown in Figure 5.

A turbine using natural gas produces electric power. Gas turbine produces high quality exhaust heat that can be used in CCHP configurations to reach overall system efficiencies (electricity and useful thermal energy) of 70 to 80 percent [6][9].

Another essential directive has been design and built a power plant that as far as possible would be compatible with the environment, by drawing on the best available techniques for the production processes and the process machinery.

Based on the calculations to satisfy the energy demand of hospital, the designers have forecast the machines and equipments as following summarized:

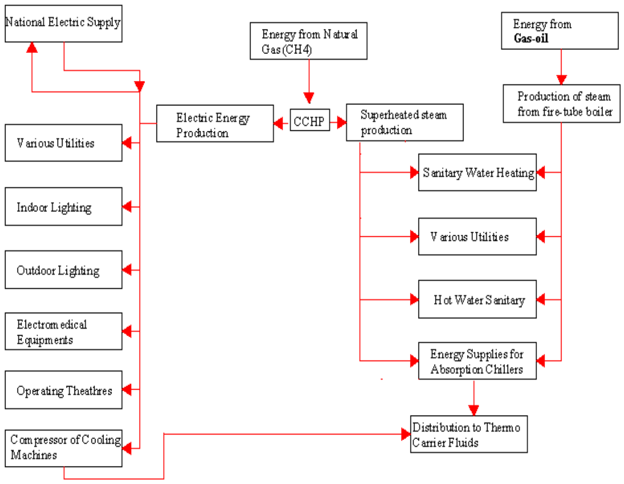

Figure 5. Architecture of System

- gas turbine, able to produce 5.250 kW of electric power
- unfired heat recovery steam generator that produces 12.750 kg/h of steam at 10 bar used into a thermal loop for hospital space heating during winter months or to feed single effect absorption chillers that provide cooling power during the summer
- electric power generators, able to produce 600 kW of electric power
- three steam generators, each one able to produce about 5.000 kg/h of steam, that is about 2.780 kWt
- Two electric chillers, each one able to produce 4.079 kW of cooling power
- Two absorption chillers, each one able to produce 4.037 kW of cooling power

For standard operating conditions, the energetic demands will be satisfy as shown in Table II.

TABLE II. POTENTIAL OF SUPPLYING

Peak Demand	**Machines**	**Supply**	**%**
Thermal (kW)	Heat recover steam generator	8.850	87
10.097	Steam generator	2.730	23
	Total	*11.580 kWt*	100
Steam (kg/h)	Heat recover steam generator	12.750	53

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24.174	Steam generators (n.3)	15.000	47
	Total	*27.750 kg/h*	
Cooling(kW) *11.071*	Absorption chillers (n.2)	8.174	74
	Electric Chiller (n.1)	4.079	26
	Total	*12.253 kWf*	100
Electric (kW) *4.591*	Turbo-alternator	5.125 kWe	100

The plant has supplemented by other machines and equipments like: Air Treatment Units (ATU), cooling towers, compressors, pumps, tanks, vessels, heat exchangers and so on. The Gas Turbine is able to produce about 5,25 MWe at steady state condition, and, in meantime, to discharge a flow of about 87.840 kg/h of exhaust gas at 500°C.

The thermal energy contained in exhaust gas is utilized to feed the heat recovery steam generator able to generate about 12.750 kg/h of superheated steam in is turn utilized to feed subsequent thermal exchanges :

- heat exchangers to produce hot water at 80°C for the heating utilities;
- heat exchangers to produce hot sanitary water at 48.5 °C, whilst the temperature forecasted in hot water storage tank is about 62°C
- the two absorption chillers
- post heating exchangers of air treatment units (ATU)
- various utilities ad equipments of hospital

C. Critical States of Energy Supplying

There are three possibilities to have critical state for the supplying of energy to systems:

- Critical state n.1: blackout in national electric network.
- Critical state n.2: ordinary or extraordinary maintenance of the gas turbine
- Critical state n.3: blackout for the grid distribution of natural gas

For each one of previous critical states, thanks both to three possibilities of energy supply and to all the machines and equipments foreseen, the hospital system will be always able to offer health services to the users. The strategies to solve the problem of energy supply, caused by previous critical states, are shown in Table III.

TABLE III. ENERGY SUPPLY IN CRITICAL EVENTS

Critical State 1	**Peak Demand MW**	**Machines and Equipments avalaible**	**Available Power MW**	**% of backup**
Blackout in National Electric Network	Thermal load 10,10	Heat recovery steam generator	8,85	100
		n.1 Steam generator	2,73	
			11,58	
	Cooling Load 11,07	n.2 Absorption chillers	8,17	100
		n.1 Chiller	4,08	
			12,25	
	Electric Load 11,07	Gas Turbine	**5,12**	100
	Steam load 24,17 t/h	Heat recover steam generator	12,75	100
		n.3 Steam generators	15,00	
			27.750 t/h	
Critical State 2	**Peak Demand MW**	**Machines and Equipment**	**Available Power MW**	**% of backup**
Gas Turbine Maintenance or fault	10,10	n.3 Steam generators	**8.340 kWt**	82
	11,07	n.2 Absorption chillers	**8.158 kWf**	74
	11,07	National electric network	**4.591 kWe**	100
	14,47 t/h	n.3Steam generators	**15,0 t/h**	100
Critical State 3	**Peak Demand MW**	**Machines and Equipment**	**Available Power MW**	**% of backup**
Blackout for Gas Supply (only Gas-oil storage 60.000 l)	10,10	n.3 Steam generators (Gas-oil feeding)	**8,34**	82%
	11,07	n.2 Chillers	**8.158**	74%
	4,59	National electric network	**4,591**	100
	17,66 t/h	n.3 Steam generators (Gas-oil feeding)	**15,0 t/h**	85%

The storage tank of design containing about 60.000 l of Gas oil will be able to satisfy energetic demand of critical states reported in Table III for 60 hours; that is one period of time quite enough to eliminate the cause of critical state.

III. ENERGY FLOW AND FINANCIAL ADVANTAGES

CCHP often can offer financial advantages over power purchased from a local utility or produced by other energy systems. Moreover, CCHP system creates an additional revenue stream by allowing hospitals to sell surplus electricity back to their utilities. A hospital’s ability to do this depends on the net metering and rate policies of its utility. Typically, “selling back” during off-peak hours is not profitable for a hospital, but, given the right circumstances, it can be a revenue generator during peak hours.

The baselines of Italian rules starts up the so called “Green Certificates Market” that allows to producers of electric energy by alternative sources to sell their Green

Certificates to producers that do not make use renewable sources.

In accordance with Italian legislation [10][11][12], on the efficient use of fuels, the CHP plants can obtain incentives, like exemption from having to buy Green Certificates and priority dispatching of the electricity it produce, if the Energy Recovery Index (ERI) and the Thermal Limit (TL) are, respectively, at least 10% and 15%.

The Energy Recovery Index quantifies the saving of primary energy achieved by a section of cogeneration compared to the separate production of the same quantities of electrical and thermal energy.

The Thermal Limit quantifies the amount of useful thermal energy produced annually compared to the total production of electricity and heat.

Another verification is request for the Energy Index (Ien) and it fixes the smallest values (0,51) to identify CCHP as renewable source;

The Energy Recovery Index defined by Decree No. 79/99, corresponding to the PES (Primary Energy Saving) introduced with the European directive 2004/8/CE that fixes the "high efficiency of plants" if it is verified a PES more than 10%. More punctual technical definition of previous indexes are reported in Italian Regulation previously referred.

The design of plants has been developed with the aim even to produce yearly excess of electric energy in relation to that one strictly necessary to satisfy the demand of the hospital. In this way it is possible to market the energy surplus and to have yearly economic benefits.

Table IV shows the values of main energy indexes of designed CCHP compared with that one required by technical manager of the Hospital. The value obtained by designers confirms that the CCHP system may be considered, in force of Italian regulation, as a renewable source. Table IV shows the value of main energy indexes of designed CCHP in relation to that one required by terms of contract by technical manager of Hospital Enterprise. The value obtained by designers confirms that the plants may be considered, in force of Italian regulation, as renewable sources.

TABLE IV. ENERGY INDEXES

	by Contract	by Design
Ien	0,51	0,63
TL	0,50	0,65
ERI/ PES	0,25	0,28

On the basis of these indexes values, the works council of Hospital will be able to accede in Green Certificate Market to sell that amount of electric energy yearly produced but none self-consumed.

People have calculated the monthly financial fluxes shown in Table V. The reported data have calculated considering the energy fluxes, reported in Fig.6, and the average prices of free market both for natural gas (source A.S.E.C. S.p.a: €/m3 0,48) and electric energy (source Enel €/kWh 0,09 average over 24 hours).

The CCHP systems give also considerable results in terms of respect of environment. In fact these systems have higher whole system efficiency than systems that split heating and power generation. With less fuel consumed, GHG and air pollutants (like nitrogen oxides and sulphur dioxides) are reduced more than 25,000 tons per year.

TABLE V. MONTHLY FINANCIAL FLUXES

Month	Costs for natural gas supply (1) €	Costs savings for Electric Energy (2) €	Revenues for Sales of Electric Energy (3) €	Financial fluxes (4=2+3-1) €
January	272.237	246.297	161.001	135.061
February	246.340	222.461	130.848	106.969
March	189.064	158.910	32.350	2.196
April	263.937	238.352	191.290	165.705
May	272.734	246.297	182.958	156.521
June	264.204	238.352	15.566	-10.286
July	454.848	351.800	123.263	20.215
August	454.848	351.800	189.134	86.086
September	104.928	238.352	81.437	214.861
October	142.642	175.937	50.716	84.011
November	175.887	175.937	61.694	61.744
Total Yearly	3.114.404	2.820.432	1.270.973	977.001

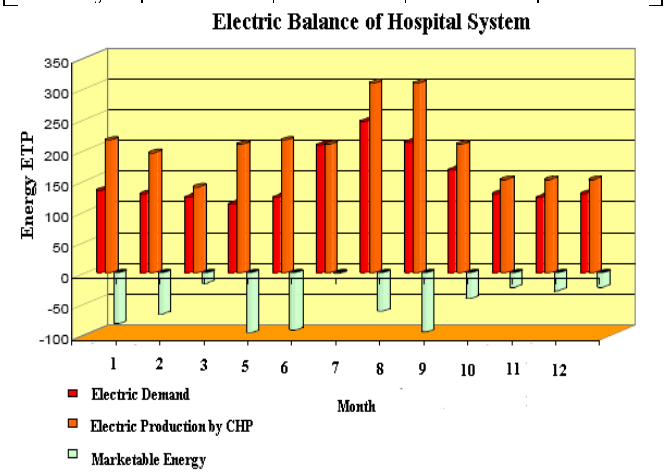

Figure 6. Monthly Trend of Electric Energy

IV. CONCLUSION

The CCHP technique can be utilized in large public buildings with considerable results in terms both of energy saving and financial advantage.

The architecture of the proposed CCHP system allows guaranteeing 100 percent redundant power source for inpatient areas and will provide the continuity of energy supply during every critical state. The following percentage of supplies have been calculated in function of “peak demands”: in the worse case (blackout in natural gas feeding), the system will be able to guarantee the 82% of the power thermal demand, the 74% of the power cooling demand and the 100% of power electric demand. The study predicts a large potential for financial savings, approximately €1,00 M€ year.

By enabling hospitals to supply their own power, CCHP systems also provide a hedge against the rising cost of electricity.

The technique gives also considerable results in terms of respect of environment: CCHP systems have higher whole system efficiency than systems that split heating and power generation. With less fuel consumed, greenhouse gases and air pollutants (nitrogen oxides and sulphur dioxides) are reduced more than 25,000 tons per year of carbon dioxide equivalent.

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