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Evaluation of Distributed Generation Technologies in Luxury Hotels

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***Abstract*— The paper aims to examine the capabilities of the application of distributed generation technologies in tertiary sector. More in details, it intends to design a plant dedicated to the production of electricity, heat and cool and to define the optimal management conditions in order to meet the energy requirements of a luxury hotel.**

The paper has energy and environmental targets: indeed, cogeneration allows to save primary energy, in comparison to separate production, and it is therefore possible to reduce polluting emissions and greenhouse gases, thanks to lower amount of fuel required. Besides, in order to evaluate possible economic benefits, this system will be installed in Italy and for this reason a deep analysis of European and Italian legislation is carried out. In fact, these laws ensure support for cogeneration (white certificates and electricity transfer to the national electric grid) and so the micro-cogenerator, depending on the chosen operation strategy, could also bring forth interesting economic results.

Performance potentialities of systems and components that can be integrated for such application are analyzed, with reference to the current state of the art. The necessary data for the design of the systems were obtained on the field, and suitable numerical codes were developed in order to evaluate the energy, environmental and economic performance of the plant configuration proposed.

***Index Terms*—cogeneration, luxury hotel, white certificates**

I. INTRODUCTION

Cogeneration (Combined Heat and Power – CHP - production) has a long history of use in many types of industry (paper, bulk chemicals and iron steel industries, oil refineries, etc.) which have large concurrent heat and power demands. In recent years the greater availability and wider choice of suitable technology has meant that cogeneration has become an attractive and practical proposition for other ranges of applications: tertiary sector (especially hospitals, university buildings, sport centers, hotels, and so on)

In Italy cogeneration has a great diffusion. In 2013, according to data published by the Italian electrical grid (TERNA, [1]), about 49% of the thermal electricity was produced by cogeneration plants. Among these power plants, the combined cycle power plants produced about 80% of the total electricity and about 50% of useful heat produced by cogeneration plants: these power plants are very important in Italian thermal power plant park. Medium size of Italian cogeneration plants is about 20MW: going into details, the size range for each typology is as follows:

- Internal combustion engines: 1-2 MW;
- Gas turbines and back-pressure steam turbines: 5-10 MW;
- Extraction-condensing steam turbines: about 20 MW;
- Combined cycle power plants: about 120MW.

Many cogeneration plants are located in industrial sites: oil refineries, chemical plants, paper and textile industries and so on. Few cogeneration plants are connected with district heating networks, especially in North Italy where climatic conditions are more suitable for such applications [2].

Shifting part of the energy production from large centralized plants to relatively small decentralized systems for cogeneration production brings improvements in energy efficiency and energy saving, as well as economic benefits, with respect to separate production of electricity in the centralized power system and of heat in local boilers. The development of cogeneration systems is particularly relevant for relatively small-scale applications (e.g., below 10 MWe) in urban areas, including potential coupling to heat networks for larger capacities as well as micro-cogeneration for domestic applications [3]. The adoption of cogeneration systems can even be more effective when it is possible to supply, in periods with little or no heat demand, absorption chillers to satisfy the cooling demand (for instance, for air conditioning), thus obtaining high-efficiency seasonal tri-generation systems. Higher energy efficiency can also correspond to lower environmental impact in terms of CO_2 emissions with respect to separate production.

Even if micro-cogeneration has not a great diffusion in Italy (really there are very few applications), energy saving and economic benefits can be very important, especially taking into account laws that were come in force recently in Italy. For these reasons, in this paper a distributed generation for a luxury hotel, located in North Italy, has been analyzed.

II. LEGISLATIVE CONTEXT

A. European Directives

In 2004, the European Union adopted the Directive 2004/8 EC [4] whose purpose is to develop high efficiency cogeneration of heat and power based on useful heat demand and primary energy savings. The Annex II of the Directive introduces the concept of "Electricity from Cogeneration" (ECHP) :

$$E_{CHP} = C * H_{CHP} \qquad (1)$$

Where:

- E_{CHP} is the electricity from cogeneration
- C is the "*power to heat ratio*"
- H_{CHP} is the useful heat from cogeneration (calculated for this purpose as total heat production minus any heat

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produced in separate boilers or by live steam extraction from the steam generator before the turbine and so on).

The Annex III of the Directive defines the "High Efficiency Cogeneration" as the cogeneration production from cogeneration units that provides *primary energy savings* (PES, see below) at least 10% compared with the references for separate production of heat and electricity (small scale cogeneration units, installed capacity below 1 MWe, and micro cogeneration units, installed capacity below 50 kWe, must provide *primary energy savings*, that is PES>0).

The *primary energy savings*, in accordance with Annex II, shall be calculated using the following formula:

$$PES = 1 - \frac{1}{\frac{CHP\ H\eta}{REF\ H\eta} + \frac{CHP\ E\eta}{REF\ E\eta}} \qquad (2)$$

Where:

- PES is primary energy savings;
- CHP Hη is the heat efficiency of the cogeneration production defined as annual useful heat output (H_{CHP}) divided by the fuel input (F_{CHP}) used to produce the sum of useful heat output and electricity from cogeneration;
- Ref Hη is the efficiency reference value for separate heat production;
- CHP Eη is the electrical efficiency of the cogeneration production defined as annual electricity from cogeneration (E_{CHP}) divided by the fuel input (F_{CHP}) used to produce the sum of useful heat output and electricity from cogeneration;
- Ref Eη is the efficiency reference value for separate electricity production.

The efficiency reference values must be calculated according to the following main principles: (i) the comparison with separate electricity production shall be based on the principle that the same fuel categories are compared; (ii) each cogeneration unit shall be compared with the best available and economically justifiable technology for separate production of heat and electricity on the market in the year of construction of the cogeneration unit. These reference values were first published in 2006 [5] and they are differentiated by year of construction and types of fuel. Then, these values were reviewed in 2011 [6].

The methodology for determining the Electricity from Cogeneration and the others parameters involved in PES calculation was postponed to successive Decisions. After the publication of the Directive 2004/8 EC, the Decision of November 19, 2008 (2008/952/EC) [7], establishing detailed guidelines for the implementation and application of Annex II to Directive 2004/8/EC, stated that a cogeneration unit, operating with maximum technically possible heat recovery from the cogeneration unit itself, is said to be operating in full cogeneration mode and all electricity is considered combined heat and power (CHP) electricity (Fig. 1). For cases in which the plant does not operate in full cogeneration mode, it is necessary to identify the electricity and heat not produced under cogeneration mode, and to distinguish it from the CHP production. The energy input and output of the heat-only-boilers which in many cases are part of the on-site technical installations are to be excluded.

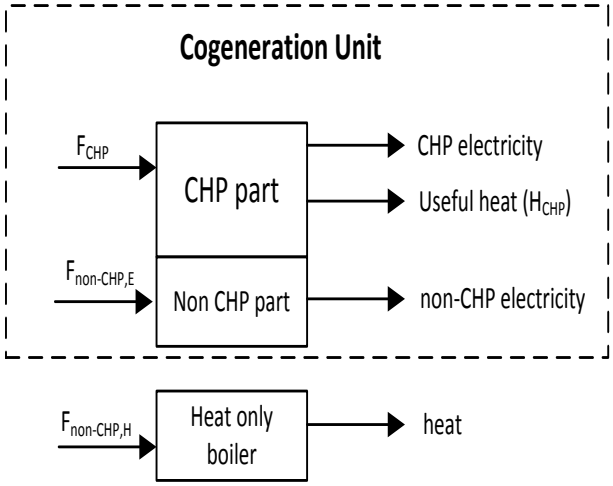

Fig. 1 – Cogeneration plant

B. Italian Transposition

Italy brought into force these laws by means of the following decrees: Legislative Decree February 8, 2007, n. 20, ministerial decree of Environment Ministry (August 4, 2011) and ministerial decree of Ministry of Economic Development (September 5, 2011) [8, 9, 10]. In February 2012 the Italian Ministry of Economic Development published detailed guidelines entitled "Guidelines for the implementation of ministerial decree of Ministry of Economic Development (September 5, 2011)" [11]. First of all, the guidelines give rules to calculate overall efficiency. To determine the overall efficiency (ηg) of a CHP plant in a reporting period, the following parameters must be known (fig.2):

- total useful heat energy (H)
- total electrical/mechanical energy (E)
- total fuel energy (F)
- non-combined useful heat energy ($H_{non-CHP}$)
- non-combined fuel energy for non-combined generation of useful heat energy ($F_{non-CHP,H}$)

CHP useful heat energy must be determined as follows:

$$H_{CHP} = H - H_{non-CHP,H} \qquad (3)$$

The overall efficiency is:

$$\eta_g = \frac{E + H_{CHP}}{F - F_{non-CHP,H}} \qquad (4)$$

If the overall efficiency (η_g) achieves or exceeds the values in Annex II of the CHP-Directive (η_{CHP}=0,80 for combined cycle gas turbines with heat recovery and steam condensing extraction turbines-based plants or η_{CHP}=0,75 for the other types of cogeneration units, i.e. steam backpressure turbine, gas turbine with heat recovery, internal combustion engine, micro turbines, stirling engines, fuel cells), the CHP plant does not generate non-CHP electrical/mechanical energy ($E_{non-CHP}$) and then:

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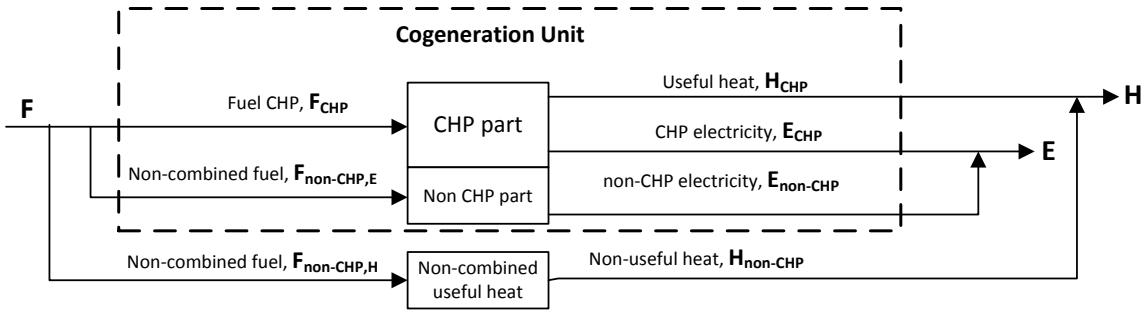

Fig. 2 – Energy of cogeneration plant

$$H_{CHP} = H - H_{non-CHP,H}$$
$$E_{CHP} = E \qquad (5)$$
$$F_{CHP} = F - F_{non-CHP,H}$$

Otherwise the non-CHP electrical/mechanical energy ($E_{non-CHP}$) and the referring fuel energy ($F_{non-CHP,E}$) have to be determined (Fig. 2); the following steps have to be done:

1) Determination of power loss coefficient (β). This parameter must be calculated for steam condensing extraction turbine-based plants. It gives the electricity loss due to steam extraction for heat production and so it is:

$$\beta = \frac{h_{estr} - h_{cond}}{h_{estr} - h_{ref}} \cdot K_p \qquad (6)$$

where:

- h_{estr} is the enthalpy of the steam extraction;
- h_{cond} is the steam enthalpy at the condenser inlet;
- h_{ref} is reference enthalpy (evaluated as the water enthalpy at 15°C e 1 bar abs)
- K_p is given by the Guidelines where there is a matrix of values differentiated by power of the steam turbine; this parameter takes into account mechanical and electric losses.

If the steam turbines have more than one extraction, the parameter β is calculated as a weighted average of the different extractions.

For all the other types of cogeneration units, it is β=0.

2) determination of the efficiency of non-combined electrical/mechanical energy generation:

$$\eta_{non-CHP,E} = \frac{E + \beta \cdot H_{CHP}}{F - F_{non-CHP,H}} \qquad (7)$$

It important to underline that the efficiency of non-combined electrical/mechanical energy generation represents a conventional efficiency of the power plant in "full electrical load".

3) determination of the power-to-heat ratio (named C_{actual}):

$$C_{actual} = \frac{\eta_{non-CHP,E} - \beta \cdot \eta_{CHP}}{\eta_{CHP} - \eta_{non-CHP,E}} \qquad (8)$$

Where η_{CHP} is equal to 0.8 for combined cycle gas turbines with heat recovery and steam condensing extraction turbines-based plants and 0.75 for the other types of cogeneration units.

4) determination of CHP electricity/mechanical energy:

$$E_{CHP} = C_{actual} * H_{CHP} \qquad (9)$$

5) determination of non-CHP electricity/mechanical energy:

$$E_{non-CHP} = E - E_{CHP} \qquad (10)$$

6) determination of fuel energy for non-CHP electricity/mechanical energy generation:

$$F_{non-CHP,E} = \frac{E_{non-CHP}}{\eta_{non-CHP,E}} \qquad (11)$$

7) determination of fuel energy for CHP electricity/mechanical energy generation:

$$F_{CHP} = F - F_{non-CHP,H} - F_{non-CHP,E} \qquad (12)$$

Using such a procedure, the CPH part of a cogeneration plant will achieve an overall efficiency exactly equal to the overall efficiency (η_{CHP}=0.8 or η_{CHP}=0.75) established in Annex II of the CHP-Directive.

C. *Italian support mechanisms*

The Italian ministerial decree of the Ministry of Economic Development [9, 10, 12] provides the following national support mechanisms: the white certificates. Their value is variable (a medium value can be considered 100 €/TOE per certificate, even if in these last year's their value was greater) and they are issued to the plant for every year in which it will demonstrate to be cogeneration plant (maximum 10 years, 15 years only for cogeneration plant for heating district). In order to calculate the number of with certificates, first of all saving must be calculated:

$$saving = \frac{E_{CHP}}{0.46} + \frac{H_{CHP}}{0.82} - F_{CHP}$$
$$saving = \frac{E_{CHP}}{0.46} + \frac{H_{CHP}}{0.90} - F_{CHP} \qquad (13)$$

Where all energy are measured in MWh and 0.82 is used when useful heat is provided by exhaust gases (directly use) and 0.9 when useful heat is provided by water/steam; this saving represents the energy saving in MWh.

The number of white certificates, WC, is then calculated as follows:

$$WC = saving * 0.086 * K \qquad (14)$$

Where 0.086 is the conversion factor (from MWh in TOE) and K is a parameter that depends on the size of power plants.

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III. THE CASE STUDY

In this paper, a preliminary analysis of technical and economic feasibility is presented with reference to a trigeneration plant, located in North Italy, that has to satisfy energy needs (electricity, heat and cool) of a luxury hotel with 145 rooms, an internal swimming pool and a wellness center (with sauna, emotional showers, steam bath, relax area, many facial and body treatments and massages).

In the present situation, heating and hot water are provided by boilers, fed by natural gas. Electricity is provided by national grid and the delivering point is at medium voltage. For summer air-conditioning compressor chillers are used; the cooling system is then composed of many air-conditioners, located in different areas of the hotel.

In Fig. 3, energy needs per month are shown [13]. In winter heating needs are very high (the hotel is located in a cold city). Electric needs for compressor chillers were not available; we have calculated them in summer by difference with the other electrical needs (lighting and motive power for equipments) in winter; then cooling needs are calculated assuming a COP (coefficient of performance) equal to 3.

In Fig. 4 examples of daily loads for the hotel are shown. In winter holidays there is a greater electric load (in comparison with winter days) because some facilities (restaurants, bars and especially wellness centre) are also home to external customers who do not reside in the hotel; in winter heat load and hot water load are not influenced by external customers. In summer holidays, all loads are greater (in comparison with summer days) because tourist presence is usually short (3 days stay on average) and especially during holidays.

About the hotel, some details are:

- Useful heated area: 5,800 m^2
- Gross heated volume: 17,400 m^3
- Electric need:1.43 GWh per year
- Heat need: 2.09 GWh per year
- Cooling need: 0.457 GWh per year
- Heat power: 800 kW
- Cooling power: 550 kW

Power to heat ratio is about 0.68 (1.43 GWh and 2.09 GWh per year respectively for electrical needs - excluded cooling needs - and heat needs). In a typical yearly operation, equivalent hours are quite low: considering heat power size of 800 kW and cooling power size of 550 kW, they are about 2600 for heat load and about 830 for cooling load.

IV. DESIGN CRITERIA AND TECHNIQUES OF OPERATION MANAGEMENT

In this paper, the prime movers were designed according to the following hypothesis: the prime mover must produce the maximum useful heat (for heat needs, including hot water, and for cooling needs, absorption chiller). The previous hypothesis depends also on the fact that in Italy the price of the electricity exported to the grid is quite low in comparison with the price of 'top-up electricity': for this reason is important to consume on-site all the electricity produced.

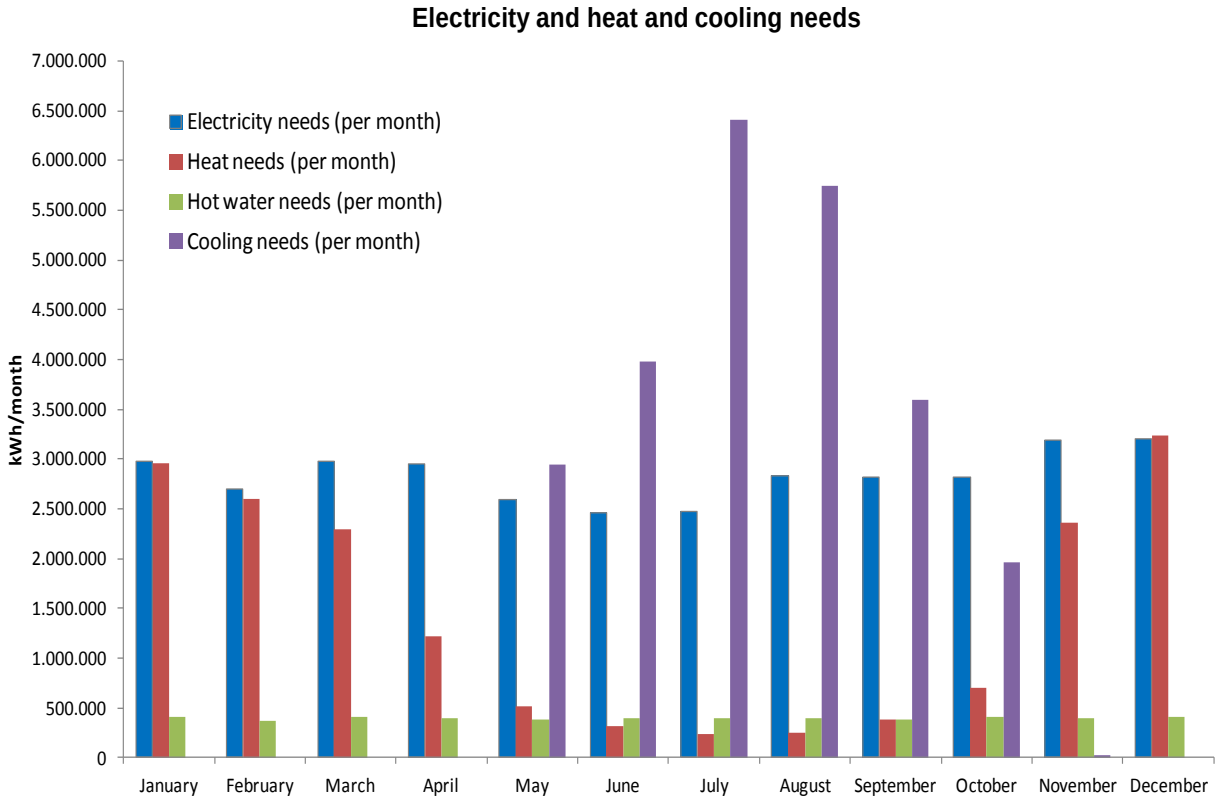

Fig. 3 – Electricity, heat and cooling needs in the luxury hotel

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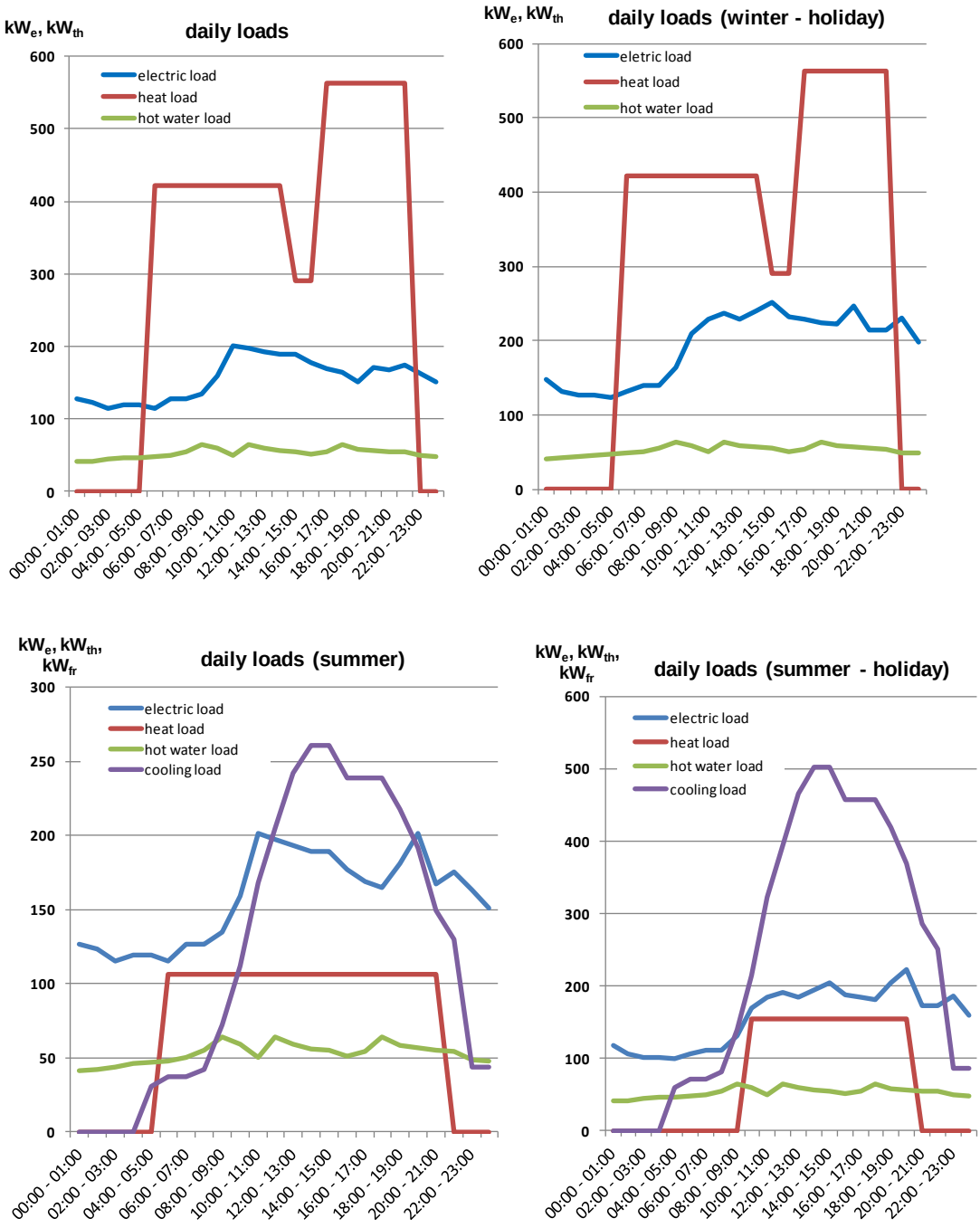

Fig. 4 – Daily loads of luxury hotel in winter and summer

In this paper three different techniques of operation management were chosen:

- '100% of load': in this case the prime mover works at the maximum power. If electricity demand is greater than electric output of the prime movers, electricity is imported by the grid; vice versa, if electricity demand is lower than electric output of the prime movers, electricity is exported to the grid. If heat demand is lower than heat output of the prime movers, part of heat is rejected to the environment without any beneficial use; vice versa if heat demand is lower than heat output of the prime movers, the cogeneration system must be equipped with an auxiliary boiler;
- 'Follows electric load': in this case the prime mover must satisfy electricity demand. In each condition, if heat demand is lower than heat output of the prime mover, the cogeneration system must be equipped with an auxiliary boiler. This technique avoids import and export of electricity;
- 'Follows heat load': in this case the prime mover must satisfy heat demand. In each condition, if electricity demand is greater than electrical output of the prime movers, electricity is imported by the grid; vice versa, if electricity demands is lower than electric output of the

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prime movers, electricity is exported to the grid.

Cogeneration system design and results of the different techniques of operation management are elaborated using a proper calculation code, developed by authors.

100% of load

In order to minimize heat rejection, prime mover size is chosen according to the minimum heat load. In this case the cogeneration system must be equipped with an auxiliary boiler. But also electric load (maximum and medium) must be considered: if power (maximum/medium) to heat (minimum) ratio of the consumer is much lower than power to heat ratio of the prime mover, it means that the consumer needs more heat than that produced by prime mover. In this case the prime mover size can be chosen according to the maximum electric load. Greater electric sizes are not proposed because the price of electricity exported to the grid is quite low.

'Follows electric load'

In this case, prime mover size is chosen according to the maximum power load. But also heat load must be considered: if power (maximum/medium) to heat (minimum) ratio of the consumer is much lower that power to heat ratio of the prime mover, it means that the consumer needs more heat than that produced by prime mover. In this case the prime mover size can be chosen according to the maximum electric load. Vice versa, if power (maximum/medium) to heat (minimum) ratio of the consumer is greater than power to heat ratio of the prime mover, it means that the consumer needs less heat than that produced by prime mover. In this case the prime mover size can be chosen according to the minimum heat load and electric demand must be satisfied importing electricity from the grid.

'Follows heat load'

In this case, prime mover size is chosen according to the medium heat load. In this case, the changeability of heat demand must be considered: in fact, if heat demand is much changeable during the day, the prime mover must follow this demand and so it can work in off-design in many period and the electric efficiency decreases. If heat demand is regular during the day, electric load (maximum) must be considered: if power (maximum) to heat (medium) ratio of the consumer is much lower that power to heat ratio of the prime mover, it means that the consumer needs more heat than that produced by prime mover. In this case the prime mover size can be chosen according to the maximum electric load because the price of electricity exported to the grid is quite low. Vice versa, if power (maximum) to heat (medium) ratio of the consumer is greater than power to heat ratio of the prime mover, it means that the consumer needs less heat than that produced by prime mover. In this case the prime mover size can be chosen according to the medium heat power. In this case electric demand must be satisfied importing electricity from the grid.

V. COGENERATION SYSTEM DESIGN AND RESULTS

A. *Figures and Tables*

In Tab. I, sizes of the main components of the cogeneration system (chosen following the previous procedure) are shown. This choice has achieved the best energy results.

Table. I – Sizes of main components of cogeneration system

		100% load	follows electric load	follows heat load
prime mover (ICE)	kW	250	220	290
absorption chiller	kW	510	510	510
auxiliary boiler	kW	650	750	550

In Tab. II, the main energy results are shown. The main conclusions are here discussed:

- Prime mover: in the first two operation management techniques working hours are very high (over 7800 hours that is an utilization factor greater than 90%); in the last operation management technique working hours are lower (about 6200 hours that is an utilization factor greater that 70%). On the basis of this last result, it is clear that there is a quite large period of time where heat load is so lower that the prime mover is turned off.
  The medium load factor of the prime mover (equivalent hours to working hours ratio) is very high: from 75% in the second operation management technique to 90% and 100% for the other two operation management techniques (follows heat load and 100% load respectively). For this reason the electric efficiencies are very similar to the design efficiency except for the second operation management technique.
  Electric production can satisfy a lot of electric need of the consumer (over 90%); heat production can satisfy completely heat need (including hot water) of the consumer.
- Absorption chiller: the size of this component was chosen in order to satisfy the maximum cooling load. In this situation, heat load of the absorption chiller is higher than heat load of the prime mover and so an auxiliary boiler was included in the cogeneration system in order to satisfy heat need of the absorption chiller. If a reversible heat pump (compression chiller) was included in the cogeneration system, the size of the absorption chiller would be correlated to the heat production of the prime mover and the cooling need would satisfied using both compression and absorption chillers. In this last case, a lot of cooling heat is produced by compression chiller and so electricity need must be considered. Working hours are high, but equivalent hours are low because the absorption chiller is sized on maximum cooling load.

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Table. 2 – Energy results

		present situation	Cogeneration system		
			100% of load	follows electric demand	follows heat demand
Needs of the consumer	Electric need (MWh)	1.430,1	1.430,1	1.430,1	1.430,1
	hours of electrci need	8.760	8.760	8.760	8.760
	Heat need (MWh)	2.085,5	2.085,5	2.085,5	2.085,5
	hours of heat need	5.912	5.912	5.912	5.912
	Hot water need (MWh)	463,6	463,6	463,6	463,6
	hours of hot water need	8.760	8.760	8.760	8.760
	Cooling need (MWh)	457,2	457,2	457,2	457,2
	hours of cooling need	2.460	2.460	2.460	2.460
Prime mover	Electric production (MWh)	0	1.958,0	1.307,8	1.630,0
	Heat Production(MWh)	0	2.520,6	1.709,3	2.242,2
	Useful Heat (MWh), H_{CHP}		1.967,1	1.459,4	2.242,2
	Fuel (kStm^3, natural gas)	0	569,8	406,4	481,9
	working hours	0	7.876	7.876	6.234
	equivalent hours	0	7.832	5.945	5.621
Absorption chiller	Heat need (MWh)	0	600,9	602,0	602,0
	cooling production (MWh)	0	457,2	457,2	457,2
	working hours	0	2.460	2.460	2.460
	equivalent hours	0	897	897	897
Compression chiller	Electric need (MWh)	132,4	0	0	0
	cooling production (MWh)	457,2	0	0	0
electricity import/export	Import (MWh_e)	1.562,5	113,6	122,3	363,3
	electricity purchase (k€)	253,1	18,40	19,81	58,85
	Export (MWh_e)	0	641,5	0,0	563,2
	Electricity sale (k€)	0	48,1	0,0	42,2
Auxiliary boiler	Heat Production(MWh)	2.549,1	1.182,9	1.691,7	908,8
	Fuel (kStm^3, natural gas)	319,4	148,2	212,0	113,9

Table. 3 – Primary energy saving

		Cogeneration system		
		100% of load	follows electric demand	follows heat demand
Primary Energy Saving	E (MWh)	1.958,0	1.307,8	1.630,0
	H_{CHP} (MWh)	1.967,1	1.459,4	2.242,2
	Overall efficiency	73,37%	72,52%	85,58%
	$\eta_{non\ CHP\ E}$	36,60%	34,27%	36,02%
	C_{eff}	95,31%	84,16%	
	E_{CHP} (MWh)	1.874,9	1.228,2	1.630,0
	$E_{non\text{-}CHP}$ (MWh)	83,09	79,57	0,00
	$F_{non\text{-}CHP,E}$ (MWh)	227,0	232,1	0,0
	F_{CHP} (MWh)	5.122,7	3.583,5	4.524,9
	Electricity for own consumption (%)	67,24%	100,00%	65,45%
	CHP Eη	36,60%	34,27%	36,02%
	CHP Hη	38,40%	40,73%	49,55%
	Ref Eη	49,25%	48,90%	49,27%
	Ref Hη	90,00%	90,00%	90,00%
	PES	***14,52%***	***13,30%***	***21,98%***
	saving (MWh)	1.139	708	1.510
	saving (TEP)	***98***	***61***	***130***
	K	1,40	1,40	1,40
	N° white certificates	**137**	**85**	**182**

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Table. 4 – Economic results

		present situation	Cogeneration system		
			100% of load	follows electric load	follows heat load
Economic balance	**Proceeds (k€)**				
	- Electricity sale (k€)	0,000	48,113	0,000	42,240
	- White Certificates (k€)	0,000	13,721	8,532	18,192
	Costs (k€)				
	- CHP Fuel (k€)	0,0	313,4	223,5	265,1
	- Boiler fuel (k€)	228,2	81,5	116,6	62,6
	- Electricity (k€)	251,6	16,1	18,9	52,5
	- Maintenance (k€)	12,7	68,5	45,0	57,0
	Annual settlement (k€)	-492,5	-417,7	-395,5	-376,8
	Annual saving (k€)	0,0	74,8	97,0	115,7
	Total investment (k€)		-555,6	-513,6	-610,8

- Electricity import/export: electricity import is low (110-365 MWh) while the electricity export is great(550-650 MWh), except, obviously, in the second operation management technique where there is no electricity export.
- Auxiliary boiler: heat production of the auxiliary boiler is only a part of the total heat required (for heating, hot water and absorption chiller) and it becomes little in the third operation management technique.

In Tab. 3, the main results, correlated to the primary energy saving (PES), are shown. The main conclusions are here discussed:

- Overall efficiency: it is very high (72-86%) but the system generates non-CHP electricity ($E_{non\text{-}CHP}$). All electricity produced is E_{CHP} only in the last operation management technique.
- Electricity for own consumption: this percentage is high (65-70%) and it demonstrates that the design of the system is good.
- Primary energy saving: this value (13-40%) is much higher than the minimum value fixed by the CHP-Directive (0%).

All the three solutions achieve energy and environmental benefits as well as economic advantages (electricity sales and white certificates and thus yearly economic returns of about 8.5-62 k€). In order to complete this analysis, economic performance would have to be calculated. A simplified economic analysis was carried out and yearly economic saving of about 75-116 k€ was calculated (Tab. 4). The main economic performance parameters are: a internal rate of return (IRR) of about 6-14% after ten years and a payback period (PBP) of about 5.3-7.4 years. These economic performance is very interesting. Moreover, the economic performance can be increased if a reversible heat pump (compression chiller) is included in the cogeneration system; in fact, in this last case, part of cooling heat can be produced by compression chiller, and so electricity need must be considered, but the absorption chiller can be fed by heat discharged by prime mover, without any auxiliary boiler. From an economic point of view the best solution, here analyzed, is 'follows heat demand' (IRR= 13.6% and PBP= 5.3 years) because it involves the minimum heat production by auxiliary boiler, a low net balance for electricity import/export and the maximum number of white certificates.

VI. CONCLUSION

In this paper, a deep analysis of European and Italian legislation, regarding high efficiency cogeneration of heat and power, is carried out.

Then, the capabilities of the application of distributed generation technologies in a luxury hotel have been investigated. The final objective was the design of a cogeneration system dedicated to the production of electric, heat and cooling needs and the choice of the optimal operation management technique in order to achieve energy and environmental benefits. Performance potentialities of systems and components integrated in such applications are analyzed, with reference to the current state of the art. The necessary data for the design of the systems were obtained on the field, and suitable numerical codes were developed in order to evaluate the energy, environmental and economic performance of the plant configuration proposed.

All the three solutions proposed achieve energy and environmental benefits (PES = 13-22 %) as well as economic advantages (white certificates and thus yearly economic returns of about 9-18 k€). A simplified economic analysis was carried out and yearly economic saving of about 75-116 k€ was calculated. From an economic point of view the best solution is 'follows heat load'.

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