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Techniques of CCHP as a right way to apply the 2nd Law of Thermodynamic: case study (Part Two)

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Short summary of "Part One"

"Part one" [1] showed principal characteristics of architecture and plants of a new "Hospital in Catania city" (CH). CH was designed for about 750 beds for various medical braches; actually the building construction are nearly at the end with a final global cost of around € 145,000,000. Authors were designers of an "Efficient Energy System" (EES) [2] for needs of CH funded with more than € 18,000,000. "Part one" illustrated :

- Architectural features of buildings (Fig.1).
- Machineries, equipments, CCHP plants and other technological utilities components of the thermodynamic architecture of EES (Fig.2).

Given Italian Regulation Decrees, energy produced by CCHP plant is assimilated to energy produced by renewables energy when production happens in full compliance with well defined parameters as expected in EES design. EES was developed on the basis of "2nd Law of Thermodynamics" that allows to utilize the same thermal energy coming from one source more times for different supplyings. This is possible if there are different and decreasing intervals of temperatures for each supplying. In this way people obtain significantly energy saving with consequence of a lower amount of wasted energy in comparison with traditional energy system and a lower production too of environmental pollutants.

Abstract

Through data of consumption of various kinds of energy expected for operational EES as in executive design, it was possible to calculate the amount of air polluting emission (CO_2, NO_x, PM_{10}) produced by energy plants. Similarly it was possible to calculate emissions of the same amount of energy wasted by CH but in the case of energy supply by conventional technologies and plants. "Part two" of paper shows the result of comparison between emission coming from operational EES and emission in the case of energy supply by conventional technologies and plants. Results demonstrate how much pollution energy supply by EES takes away, that is the environmental advantages achieved.

Key Words

Energy System, Environment, CCHP, Hospital

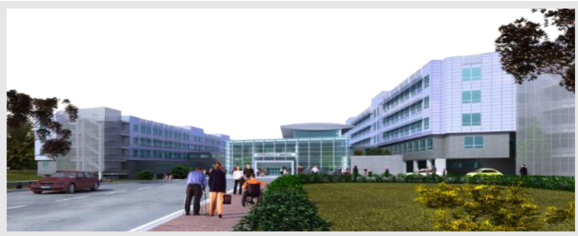

Fig.1 – CH Perspective Est

1. Efficient Energy System (EES)

A gas turbine (Typhoon of Siemens) powered by methane and coupled with an Alternator and an Heat Recovery Steam Generator (HRSG), supplies 5,25 MW_e electrical power, that is more than amount needed by CH during operation. Following the basis of "2nd Law of Thermodynamics", thermal energy abundantly contained in exhaust of gas turbine, continuously at

intervals of temperature well-defined and with decreasing values of temperature for each interval, powers a sequence of CH operational functions.
By appropriate heat exchange with water, thermal energy is exploited to produce low pressure steam to power machine based on "cooling absorption cycle" to produce cold water (5÷6 °C), to produce hot sanitary water, to produce hot water for various utilities, to feed HVAC plants and so on. Fig. 2 [1] shows the final energy architecture of EES.

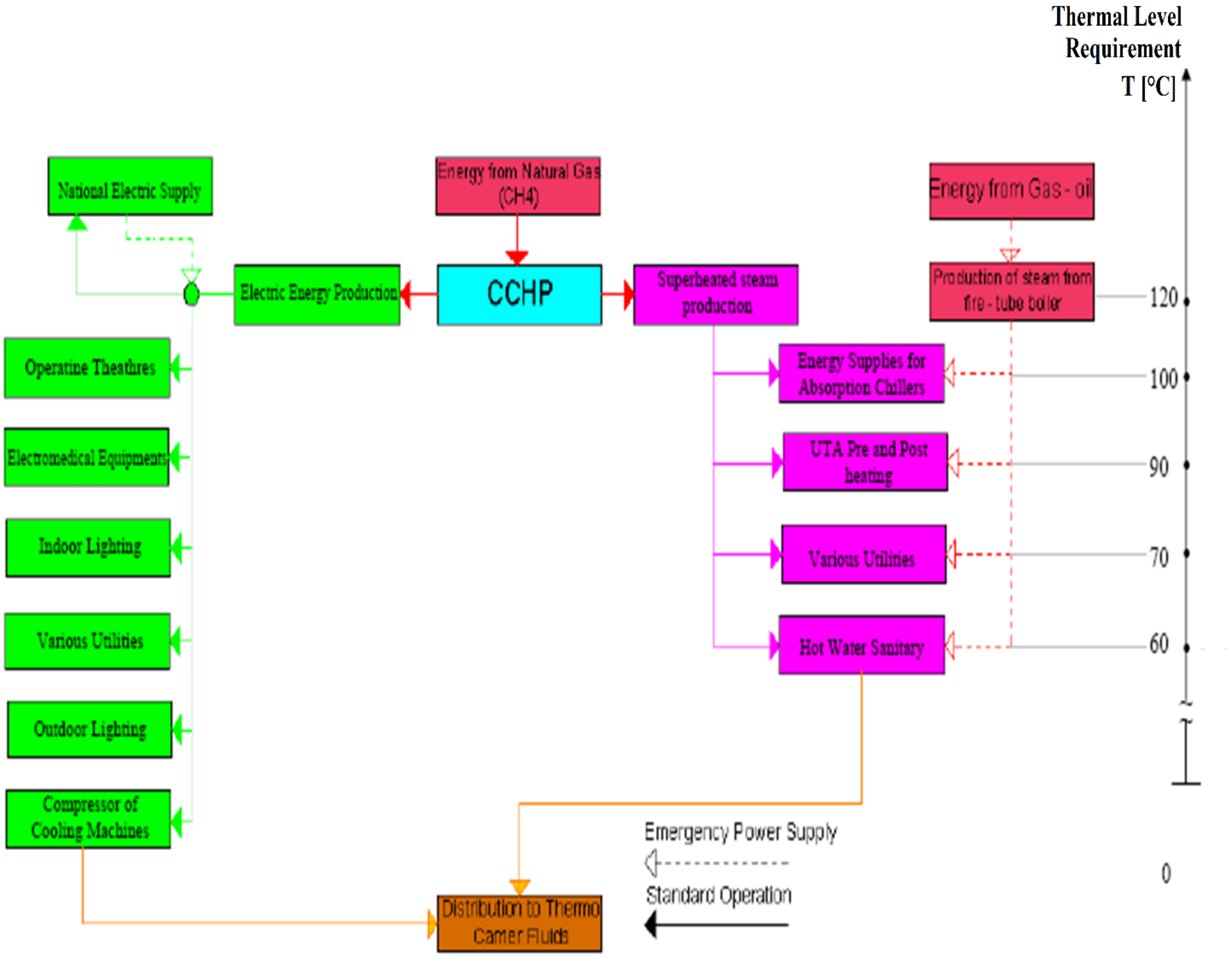

Fig. 2 – Architecture of EES

2. Energy required from CH

Table nn. 1, 2, 3 and fig.3 here after showed are coming from calculations reported in 3rd and 5th paragraphs of "Part one" of paper [1].
Tab. 1 shows the way to calculate the total equivalent hours of operation of CCHP by use of percentage value (ε) of full load operation in function of expected real operational times (see 3rd paragraph of "Part one").
Tab.2 shows electrical power request for indoor and outdoor lighting and for various utilities (electrical equipment, etc. etc.) (see 3rd paragraph of "Part one").
Data of Tab.2 come from a cognitive survey carried out on three Sicilian hospitals about similar as regard volumes of buildings, medical branches and operational electrical data essential to operation of machineries, equipments and so on so as considered in executive design of plants.
Tab.3 shows heat power request for each technical function of CH. Methodology to find data was the same previously illustrated.
Fig.3 shows in which quantity will supply various kinds of energy in function of utilization of cogeneration group, electrical network, machine at absorption or compression cycle in the case of peak of thermal and electrical request (see 5th paragraph of "Part one").

Months	Days	Operating time (h)	% of full-load operation ε	Equivalent time of full-load (h)	Total equivalent (h)
January	31	24	70	16,80	520,8
February	28	24	70	16,80	470,4
March	31	24	70	16,80	520,8
April	30	24	70	16,80	504,0
May	31	24	70	16,80	520,8
June	30	24	100	24,0	504,0
July	31	24	100	24,0	520,8
August	31	24	100	24,0	520,8
September	30	24	70	16,80	504,0
October	31	24	50	12,00	520,8
November	30	24	50	12,00	504,0
December	31	24	50	12,00	520,8
Total yearly	**365**	**8.760**			**6,133.0**

Tab. 1 – Equivalent hours of operation of CCHP system (operative turbogas)

Unit of air treatment	815 kW_e
Outdoor lighting	60 kW_e
Indoor lighting	350 kW_e
Electrical medical equipments	1,200 kW_e
Centrifugal compressors (n. 14)	3,219 kW_e
Medical operation rooms (n. 14)	560 kW_e
Various utilities	936 kW_e
Total amount	**7.140 kW_e**

Tab. 2 – Request of electrical power of CH

Summer time	**[kW_t]**	**Winter time**	**[kW_t]**
Hot sanitary water	1,425	Hot sanitary water	1,425
Cooling batteries for U.T.A.	538	Post heating (HVAC)	5,650
Absorption cooling machines	12,887	Hot separated circuits	1,415
Various utilities	1,650	Various utilities	1,650
Total amount	**16,500**		**10,140**

Tab. 3 – Request of thermal power of CH

Kind of operation	Electrical request [MW_e]	Electrical supply [MW_e]	Thermo-refrigerating request [MW_t]	Thermo-refrigerating supply [MW_t]
Full load operation	7.14	5.125	16.5	8.25
		2.02		8.25
Various intermediate loads operation	Automatic variation of loads controlled by computer programs			
First emergency op.	4.28	5.125	8.33	8.85
Second emergency op.	4.28	7.14	8.33	8.33

cogeneration group   electrical network   machine at absorption cycle

machine at compression cycle   fire-tube boiler

Fig.3 – Types of management

3. Pollutants really discharged into atmosphere

Defining:

Heat rate of turbogas (Fig.4) : 11,763.5 KJ/MWh (1)
Electrical yearly energy produced by turbogas :
5.25 MW · 6.133 h (see tab. 1) = 32,198.25 MWh/year (2)

Single-shaft SGT-100 for power generation	
Power output	5.05 MW(e) / 5.4 MW(e)
Fuel	Natural gas / liquid fuel / dual fuel; other fuels on request
Automatic changeover from primary to secondary fuel at any load	
Frequency	50/60 Hz
Electrical efficiency	30.2 % / 31.0 %
Heat rate	11,914kJ/kWh / 11,613kJ/kWh
Turbine speed	17,384 rpm
Compressor pressure ratio	14.0:1 / 15.6:1
Exhaust gas flow / temperature	19.5kg/s, 545°C / 20.6 kg/s, 531°C

Fig.4 [3]

From (1) and (2) it is possible to obtain :

11,763.5 · 32,198.25 = 378,764,113,875 KJ/year =
= 378,764.114 GJ/year (3)

The value of 378,764.114 GJ/year is the thermal energy must be powered by combustion of methane to supply turbogas. The mass of main pollutants in the case of combustion of 1GJ of methane [4] are:

$$\left.\begin{array}{l} CO_2 : 50.95\ \text{kg/GJ} \\ NO_x : 4.201 \cdot 10^{-2}\ \text{kg/GJ} \\ PM_{10} : 2.0 \cdot 10^{-5}\ \text{kg/GJ} \end{array}\right\} \quad (4)$$

From (4) and (3) it is possible to calculate the amount of polluting emission for each kind of pollutant matter:

$$\left.\begin{array}{l} \mathbf{CO_2} : 50.95\ \text{kg/GJ} \cdot 378{,}764.114\ \text{GJ/year} = \\ \quad = 19{,}298.03\ \text{t/year} \\ \mathbf{NO_x} : 4.201 \cdot 10^{-2}\ \text{kg/GJ} \cdot 378{,}764.114\ \text{GJ/year} = \\ \quad = 15.912\ \text{t/year} \\ \mathbf{PM_{10}} : 2.0 \cdot 10^{-5}\ \text{kg/GJ} \cdot 378{,}764.114\ \text{GJ/year} = \\ \quad = 0.0075\ \text{t/year} \end{array}\right\} \quad (5)$$

4. Pollutants saved

A. Pollutants coming from power station:

People calculate pollutants that could be discharged into atmosphere in the case to supply electricity from national electrical network in place of CCHP.
Tab.4 shows efficiency of electrical power station in function of type of fuel supply. In calculation people make use of an average efficiency.

Fuel supply		Efficiency	Average
Oil	=	0.45	0.43
Coal	=	0.40	
Methane	=	0.44	

Tab.4

From (2) and Tab.4 it is possible to calculate the yearly electrical energy production:

32,198.25 MWh/year / 0.43 = 74,879.65 MWh/year (6)

Potential specific emission of each kind of fuel by public electrical network [5] is showed in (7):

$$
\left.\begin{array}{l}
CO_2 : \ 0.47 \ t/MWh \\
NO_x : \ 3.1 \cdot 10^{-4} \ t/MWh \\
PM_{10} : 3.0 \cdot 10^{-6} \ t/MWh
\end{array}\right\} \qquad (7)
$$

Finally, from (6) and (7) people calculate the pollutants saved as showed in (8):

$$
\left.\begin{array}{l}
\mathbf{CO_2} : 0.47 \ t/MWh \cdot 74{,}879.65 \ MWh/year = \\
\quad = 35{,}193.44 \ t/year \\
\mathbf{NO_x} : 3.1 \cdot 10^{-4} \ t/MWh \cdot 74{,}879.65 \ MWh/year = \\
\quad = 23.213 \ t/year \\
\mathbf{PM_{10}} : 3.0 \cdot 10^{-6} \ t/MWh \cdot 74{,}879.65 \ MWh/year = \\
\quad = 0.225 \ t/year
\end{array}\right\} \quad (8)
$$

B. People calculate pollutants could be discharged into atmosphere in the case to utilize thermal generating station in place of CCHP system.
The need of thermal energy is showed in Tab.5.
Tab.6 [coming from (4) and Tab.5] shows for each utilization and for each pollutant the amount of pollutants.

	POTENZA kW	h / day	day / year	TOT. [kWh/year]	TOT. [GJ/year]
Hot sanitary water	1,425	12	365	6,241,500	22,469.4
Absorption cooling machines	12,887	8	120	9,278,640	33,403.10
Post heating (HVAC)	5,650	6	120	5,424,000	19,526.4
Hot separated circuits	1,415	8	120	679,200	2,445.12
Various utilities	1,650	3	300	1,485,000	5,346.00
Total amount				**23,108,340**	**83,190.024**

Tab.5

Utilization	Pollutant	[GJ/year]	[kg/GJ]	[kg/year]	[t/year]
Hot sanitary water	CO_2	22,469.4	50.95	1,144,815.93	1,144.8
	NO_x		$4.201 \cdot 10^{-2}$	943.94	0.944
	PM_{10}		$2.0 \cdot 10^{-5}$	0.45	$4.5 \cdot 10^{-4}$
Absorption cooling machines	CO_2	33,403.10	50.95	1,701,887.95	1,701.9
	NO_x		$4.201 \cdot 10^{-2}$	1,404.26	1.4
	PM_{10}		$2.0 \cdot 10^{-5}$	0.67	$6.7 \cdot 10^{-4}$
Post heating (HVAC)	CO_2	19,526.4	50.95	994,870.1	994.9
	NO_x		$4.201 \cdot 10^{-2}$	820.31	0.82
	PM_{10}		$2.0 \cdot 10^{-5}$	0.39	$3.9 \cdot 10^{-4}$
Hot separated circuits	CO_2	2,445.12	50.95	124,578.86	124.6
	NO_x		$4.201 \cdot 10^{-2}$	102.72	0.103
	PM_{10}		$2.0 \cdot 10^{-5}$	0.05	$5.0 \cdot 10^{-5}$
Various utilities	CO_2	5,346.00	50.95	272,378.7	272.4
	NO_x		$4.201 \cdot 10^{-2}$	224.59	0.225
	PM_{10}		$2.0 \cdot 10^{-5}$	0.11	$1.1 \cdot 10^{-4}$

Tab.6

Finally in (9), originated from Tab.6, people calculate total amount of saved emission for each kind of pollutants:

$$
\left.\begin{array}{l}
\mathbf{CO_2} : \ 1{,}144.8 + 1{,}701.9 + 994.9 + 124.6 + \\
\quad + 272.4 = 4{,}238.6 \ t/year \\
\mathbf{NO_x} : \ 0.944 + 1.4 + 0.82 + 0.103 + \\
\quad + 0.225 = 3.492 \ t/year \\
\mathbf{PM_{10}} : 4.5 \cdot 10^{-4} + 6.7 \cdot 10^{-4} + 3.9 \cdot 10^{-4} \\
\quad + 5.0 \cdot 10^{-5} + 1.1 \cdot 10^{-4} = \\
\quad = 1.67 \cdot 10^{-3} \ t/year
\end{array}\right\} \quad (9)
$$

5. Environmental balance

The amount coming from (5), (8) and (9) allows to have the final environmental global balance where negative values are attributed to pollutant matters really inserted in environment by combustion of fuel (CH_4) to supply turbogas, instead of positive values are attributed to theoretical pollutant matters in the case of energy supply by conventional technologies and plants.

$$\left.\begin{array}{l} \mathbf{CO_2}: \ 35{,}193.44 + 4{,}238.6 - 19{,}298.03 = \\ \quad = 16{,}134.01 \text{ t/year} \\ \\ \mathbf{NO_x}: \ 23.213 + 3.492 - 15.912 = \\ \quad = 10.793 \text{ t/year} \\ \\ \mathbf{PM_{10}}: \ 0.225 + 1.67 \cdot 10^{-3} - 0.0075 = \\ \quad = 0.22 \text{ t/year} \end{array}\right\} \quad (10)$$

6. Conclusion

As showed previously in (10) design of EES pursuant to criteria of "2nd Law of Thermodynamics" and selecting CCHP techniques is a right way to decrease significantly impact of pollutants into atmosphere, especially for CO_2 and PM_{10}.

There is not a general methodology to design an EES; in fact the planning choice has general effectiveness as regard criteria of "2nd Law of Thermodynamics", whereas the practical consequence of CCHP techniques is convincing in application for this specific or that comparable cases that maintain specific values of ratio between electrical and thermal energy required.

It means that correct thermodynamics design of EES must take in account a lot of variable such as :

- Weather-climate and geographic position of locality of construction
- Types of activities that will carried out in built volumes
- Total amount of energy yearly required
- Possibility to exploit other renewable sources if locally present
- Etc. etc.

Only taking in consideration all previous variables, and other more, the designer will be able to conciliate the exploitation of energy and the care of environment.

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