Fitting The Cogeneration Plant To Energy Needs

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Abstract This paper proposes a scheme of cogeneration plant that allows to minimize the surplus of thermal energy and electricity produced. Using the data of consumption of thermal energy and electricity of a hospital in south Italy, it was proposed a cogeneration plant added by compression refrigerators and heat pumps and absorption refrigerators. After analyzing the thermodynamic parameters to assess the energy savings achieved as a reduction of primary energy n passing from conventional energy production to in cogeneration with integration of auxiliary machines.
It was suggest to adapt, according to the type of energy to be supplied, the components added by assessing the reduction of primary energy obtained with a scheme of this type adapted to the energy requirements monthly. The results obtained were assessed with efficiency values lower than those attributed to thermal machines to take into account that these machines are used partialized working because it supplies a power reduced with respect to the maximum possible value, then, with efficiency values lower. The results obtained have confirmed the need to fit the system to the energy requirements for the minimum consumption of thermal plants..

Key words: Cogeneration. Energy saving. Primary energy. Efficiency, Energy conversion.

Introduction

The cogeneration system uses an engine that supplies, in addition to the electricity produced, thermal energy that is rejected in traditional systems. With this kind of power plant is possible arise the efficiency up to '80% of the energy supplied to the system. These high efficiency values are valid only if the two forms of energy are used completely. Their report precise values such as 37% of electricity and 45% of thermal energy while it is hard to find users who are in need of electricity and thermal energy in the same proportion. It must take into account also that the energy needs change during the year requiring the need to heating load in winter and cooling in summer, while the ratio of the two forms of energy produced is, of course, the same. The fitting of the cogeneration plant to actual consumption of energy enables the use of cogeneration high efficiency only if there are no surplus energy. In the analysis of plant performance will not be taken into consideration opportunities, as a heat recovery system that may be not available if the cogeneration system is used in the event of refurbishing and/or the possibility of supplying any surplus of electricity to the grid because these facilitations depend on the place and the economic situation: both solutions, if active, reduce the surplus of energy and thus increase its efficiency.

The main aim is to compare the efficiency of the plant calculated in the design phase with the efficiency of the system in actual operation. It becomes important, therefore, to analyze more deeply the various configurations of the machines involved in a cogeneration plant to evaluate in a more reliable the reduction of energy consumption for the efficient evaluation of the economic convenience of the cogeneration plant.

The use of a PLC to control and manage whole the machines which constitute the cogeneration plant allows to address the energy, heat and electricity, produced to supply energy to heat pumps and refrigerators, both in compression and absorption, to maximize the reduction of energy produced. The change of the energy needs both in quantity along the hours of the day and in quality along the months of the year requires to analyze the most common configurations in order to evaluate their effects on energy consumption. To analyze the efficiency of various configurations are taken into account, in addition to the internal combustion engine as the primary source of cogeneration, absorption chillers and reverse cycle compression machines, refrigerators and heat pumps. The PLC allows also to monitor the connections of the various machines, the operating times and, therefore, to assess the effective efficiency of the whole plant with the capability to modify the intervention strategy, if necessary.

The average values and the modulation of these parameters are important in the system configuration. The electricity consumption are easily derived from the bills and the thermal one are evaluated through the amount of fuel supplied. The consumption associated with both thermal requirement that the electric ones are differentiated from the point of view of quality. With reference to the way with which the energy is transformed and the temporal variability with which they control the consumption same.

Nomenclature

COP	heat pump efficiency
E_{CCS}	conventional electrical output,
E_{CCU}	cogeneration electrical output,
E_{CoGe}	primary energy demand by the cogeneration plant,
E_E	electricity produced,
EER_{ARS}	absorption refrigerating system efficiency
EER_{CRS}	compression refrigerating system efficiency
E_{HP}	electricity power to driving the heat pumps
E_{CoGe}	electricity actually used.
E_{Tc}	civil heat produced,
E_{Ti}	industrial heat produced,
Q_{ARS}	engine thermal power for absorption refrigerators driving
Q_{EC}	primary energy of conventional cooling
Q_{CoGe}	primary energy for the cogeneration plant,
Q_{CP}	heat power to driving absorption refrigerating system
Q_H	primary energy for conventional boiler
Q_{ICE}	heating capacity,
Q_P	primary energy demand for cogeneration
Q_{UC}	cold actually used,
Q_{UH}	heat actually used,
η_B	heating burner efficiency
η_{EL}	electricity generation efficiency
η_{Tc}	civil thermal production efficiency,
η_{Ti}	industrial thermal production efficiency,

The cogeneration plant

The cogeneration or Combined Heat and Power (CHP) is substantially an engine capable to produce mechanical power and can arrange the recovery of heat from the engine in order to use it for the technological applications for high, medium and low temperatures.

The installation of a cogeneration plant becomes more convenient when you must proceed to the replacement or installation of new heat generators or motors for the production of electricity. it should be specified that in the case of civil users and unlike industrial utilities with energy demands practically constant, the analysis is complex due to the strong variations of thermal loads and electrical and non-coincidence of variation for both energies. In the face of significant changes, the cogeneration plant cannot be sized for the maximum load to avoid incurring the penalties for lower yields at partial load.

One solution is the construction of the cogeneration plant using a group of machines having powers such that their sum is equal to the maximum power. In this way, the reduction of the thermal load is answered by turning off one or more of the units allowing the others machine to operate at the maximum load leaving only one operating in partial load thus reducing losses related to the reduction in yield due to partial load. This, however, leads to an increase in the cost of the system and an amortization period longer.

The achievement of high overall performance typical of cogeneration is subject to the effective use of heat generated from the production of electricity and thus to maintain the relationship between electricity and thermal energy demand. For this purpose it would be necessary diagrams of the electrical power demand during the day type summer and winter. It is possible, then, define the trend of the annual frequency of the power produced and the power absorption. Even at this stage have a fractionation in different machines operating in parallel would help to regulate the production of energy to the request of the same. This would be possible if it remains more or less constant ratio between electricity and thermal energy produced and absorbed.

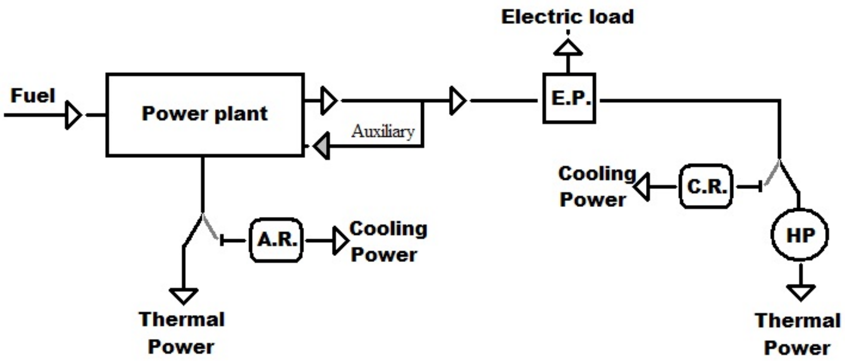

Figure 1: Schematic representation of the proposed cogeneration plant

In hospitals the production of cold is done with compression refrigerators electrically operated. This means that during the hottest hours of summer days there are high demands for electric power, not necessary in the rest of the year, that would not be possible to satisfy. It would be necessary to take such power from the electrical grid undergoing paying high rates normally linked to consumption peaks. The cogeneration plant during the summer days has a surplus of heat that can be suitably converted into cold with the use of absorption machines that can produce the necessary cold to satisfy the summer thermal load. From a thermodynamic point of view there is an increase of the quality of the system because the thermal energy produced in the summer, to be considered completely lost, is recovered in the percentage of the cooling efficiency of the absorption machine.

On cold winter days the increase of the thermal power needed to satisfy the heat load can be reduced using the more electric power produced for driving heat pumps that can provide heat in the percentage amount of the efficiency parameter, COP. Even in this case, the reduction of produced and not used energy increases the thermodynamic efficiency of the plant. Any increase in thermodynamic efficiency results in a reduction of primary energy required by the thermal plant.

To increase the flexibility of the cogeneration plant it is possible to alter the relationship between electrical and thermal energy. is possible to use compression heat pumps (moved by an electric motor) and absorption refrigeration machines. In this way if there is a greater demand of thermal energy, an increase of power supplied by the cogeneration plant would result in a surplus of electrical energy whose disposal may even lead to the disposal environment by reducing the efficiency of the plant. using the most electricity to power a heat pump of sufficient value of the COP, it is possible to reduce the power increase using the surplus of electricity supplying it to heat pump with COP value more of $1/\eta_{EL}$. reducing the power increase without any waste of energy produced. In case of increase in the demand for electricity for air conditioning in summer can be avoided by increasing proportionally the electric power generated. This would result in an increase of heat cannot be used resulting in a reduction in the efficiency of the system.

Parameters for evaluating the cogeneration effectiveness

The evaluation of the efficiency of a plant that produces heat, cold and electricity must be taken into account the efficiency with which these products are energy. The heat produced is directly characterized the performance of the burner, η_B, while the production of cold depends on the efficiency of refrigerators, EER; the obtained mechanical/electrical power is related to the energy supplied to the engine through the thermodynamic efficiency of the engine, η_{EL}. When evaluating the efficiency of energy production in a cogeneration plant production efficiencies are not directly comparable. For this reason the most effective parameter for evaluating any higher efficiency of a cogeneration plant is to evaluate the percentage of the reduction of primary energy when a cogeneration plant is involved to satisfy the heat, cold and electricity needs instead of a conventional one.

The primary energy required by a conventional system designed to produce heat, cold and use electricity is equal to the sum of primary energies required by production of the three types of energy:

$$PE_{Conv} = \frac{\sum Q_H}{\eta_B} + \frac{\sum Q_C}{EER_{CRS} \cdot \eta_{EL}} + \frac{E_{CCS}}{\eta_{EL}} \qquad (1)$$

where

$\frac{\sum Q_H}{\eta_B}$ is the primary energy demand for furnace with performance η_B,

$\frac{\sum Q_C}{EER_{CRS} \cdot \eta_{EL}}$ is the primary energy demand for refrigerators compression with efficiency parameter EER_{CRS} driven by electricity produced with performance η_{EL},

$\frac{E_{CCS}}{\eta_{EL}}$ is the primary energy demand from the production of electricity with performance η_{EL}.

The primary energy of the cogeneration power plant is the energy supplied in order to produce electric and thermal energy; as noted above cooling can be produced using heat to drive absorption refrigerator or electricity to drive compression one.

The real energy savings can be evaluated through the parameter named Primary Energy Savings defined by the following formula:

$$PES = \frac{PE_{Conv} - PE_{CoGe}}{PE_{Conv}} \qquad (2)$$

This parameter represents the reality of the energy consumption for the same meeting the energy needs satisfying; the greater thermodynamic efficiencies and/or management are these involve an actual reduction of primary energy.

European law (DIRECTIVE 2004/8/EC) states that a cogeneration plant can be regarded as a "high efficiency" in order to take advantage of incentives and facilities if the value of the parameter PES is greater than zero for power plants less than 1.0 MW and greater than 10% for power plants greater than or equal to 1.0 MW.

By inserting in the formula the values of the efficiencies of heat and electricity production the PES can be wrote as the following formula also named FERS (Fuel Energy Saving Ratio):

$$PES = 1 - \frac{Q_{CoGe}}{\frac{Q_{Tc}}{\eta_{Tc}} + \frac{E_E}{\eta_E}} \qquad (3)$$

The thermodynamic efficiency of a cogeneration system depends on the efficiency of the three components such as heat, cold and electricity. The efficiency values depend on the value of the instantaneous power because the choking of the power produced will reduce the values. The energy produced and not used cannot be taken into consideration to assess its efficiency bearing in mind that the relationship between the thermal power and the electric power generated is constant.

Using all the efficiency parameters and the percentages of the thermal energy produced by the internal combustion engine used to driving the absorption refrigerating system (Q_{EC}/Q_{ICE}) and the percentage of electricity produced by the internal combustion engine used to driving heat pump (E_{HP}/E_{CCU}) it's possible evaluate directly the variation of primary energy achievable with a cogeneration plant.

$$PES = 1 - \frac{\left[1 + \frac{E_{CCU}}{Q_{ICE}}\right]}{\left(\frac{Q_{ICE} + E_{CCU}}{Q_p}\right) \cdot \left[\left(\frac{\frac{E_{CCU} - E_{HP}}{Q_{ICE}}}{\eta_{El}}\right) + \left(\frac{1 + \left\{\frac{E_{HP}}{E_{CCU}} \cdot \frac{E_{CCU}}{Q_{ICE}}\right\} + \frac{Q_{EC}}{Q_{ICE}} \cdot EER_{ARS}}{\eta_B}\right) + \left(\frac{\frac{Q_{EC}}{Q_{ICE}} \cdot EER_{ARS}}{\eta_{El} \cdot EER_{CRS}}\right)\right]} \quad (4)$$

The cogeneration plants must be able to meet the heat demand of the technological and heat for heating, electricity for technological needs and for the production of cold necessary for the air conditioning in summer. The formula (4) expresses the possible reduction percentage of primary energy when energy needs are met with the CHP. This formula takes into account the yield at which the various forms of energy are produced. It should be noted that obtaining a reduction of primary energy used is an energy saving even in the presence of surplus energy not directly usable by the user. In this case one can think of using storage systems with regard to thermal energy or to direct any surplus electric power to the overall network.

Case of study

The object of the study hospital has about 850 beds, situated in the south of Italy consumes in a year about 1,750,000 litres of diesel and 5,000 MWh of electricity. The thermal power plant, equipped with traditional boilers, providing steam to 1.0 MPa at about 175 °C to meet the typical hospital services such as laundry, kitchen and sterilizers for both generic services such as hot water and heating in winter. There is no centralized air-conditioning plant but a room small air-conditioning.

The choice to study the application of a cogeneration system for a hospital derives from fairy for this type of users, there is well-known in literature. The thermal requirements related to heating were obtained by subtracting the heat consumption winter the heat consumption of the summer months representing the consumption of thermal energy for hospital purposes.

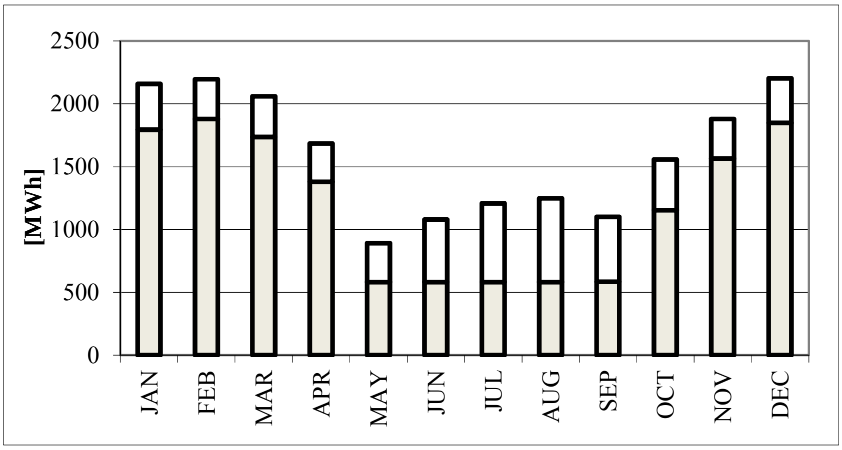

Figure 2: The thermal and electrical consumption of hospital

The monthly average thermal energy consumption (grey) and electrical ones (white) are shown in Figure 3. From the same figure is shown the increase in electricity consumption in the summer months due to the use of air conditioning. The relationship between the electrical power and thermal power is a key parameter to determine the pattern of the cogeneration plant. The plants of this type have a relationship between the two energies fairly constant which can be very different from the relationship of the needs of the hospital.

In the particular case considered is added that for security reasons, a hospital must have an ability to self-production of heat and power for the continuity of emergency services in case of power failure. This involves an economic advantage in buying, and management, the apparatus of self-production.

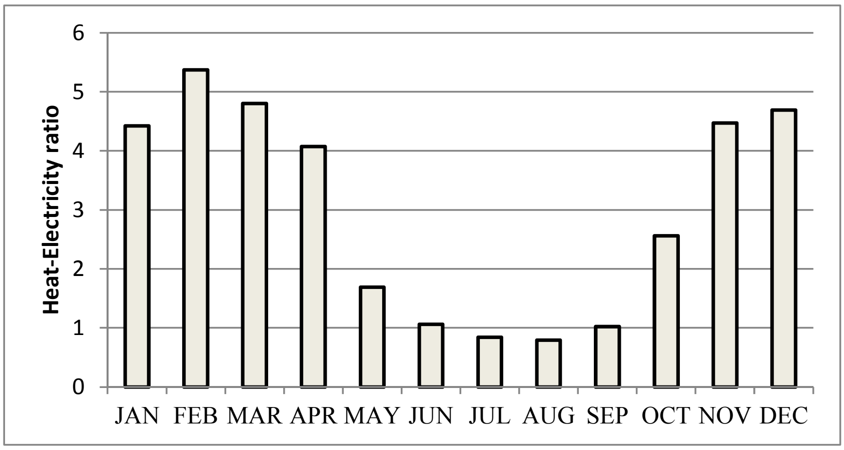

Figure 3: The ratio between the thermal and electrical energy

It is felt important to emphasize that this ability to produce energy is becoming paramount also for office buildings as the spread of the apparatuses TLC (router, wifi, and the computer itself) requires the availability of electricity is no longer available directly on the line telephone as is present on traditional phone lines.

As regards the value of the temperatures at which the heat is supplied as it is energetically more valuable the higher the temperature at which it is supplied. It is recalled that the sterilization requires 140 ° C 190 ° around the ironing, cooking little more than 100 ° C, hot water at 50 ° C and heating to around 80 ° C as well as absorption refrigeration machines. In Figure 4 shows the thermal energy at high enthalpy and the low enthalpy where we see that the heating requirements of high enthalpy is relatively low compared to that of low enthalpy.

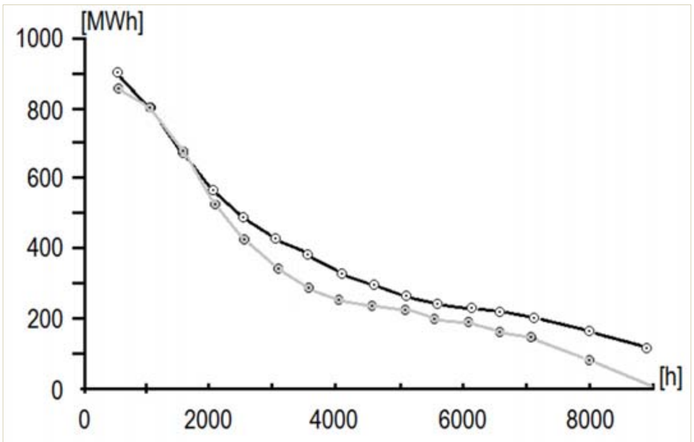

Figure 4: Total heat energy needs (black curve) and the low enthalpy thermal energy needs (gray curve).

On average, the heat consumption is divided in half between the heating and the hot water, for general uses. As regards the hot water, the percentages of utilization and the uses are indicated in the figure below.

CHP gives the ability to produce heat and electricity using about 90% of the energy supplied. The heat produced is about 58% while the electricity produced is about 32% with a ratio heat electricity equal to 1.37:1.

This high efficiency of transformation is only valid if all the electricity and all the thermal energy produced is used. If the energy requirements of thermal energy and electricity have a relationship other than that of cogeneration, the fulfillment of one leads to an imbalance of the other.

The ratio of heat and electricity energy needs required is almost always different from the relationship of cogeneration (surely it is during the day and between days) so it is needs to adapt the system to the energy requirements because the production of not used energy results as a reduction in system efficiency.

Regarding the hospital object of our analysis, in the winter period a part of the thermal power is used for technological purposes (the same throughout the year) and a part for room heating. By adjusting the heat output of CHP in order to satisfy the thermal load can have a ratio greater than the ratio heat-electricity cogeneration thus producing a surplus of electricity. Using the surplus of electrical energy to drive a heat pump would be obtained rate of heat which would reduce the thermal power produced by the motor up to the coincidence of the thermal power produced (engine plus heat pump) with the heat load, minimizing the electricity surplus.

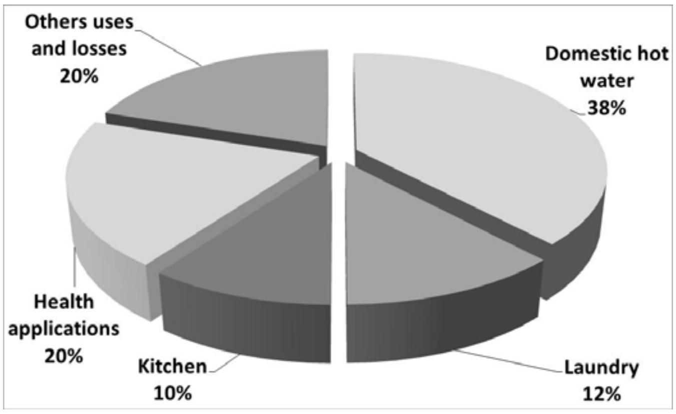

Figure 5: Percentages of the thermal energy needs in hospitals

In summer time the electricity demand is used to meet both the needs of technology (the same throughout the year) and the electrical load to produce cold for room conditioning. By adjusting the thermal power cogeneration to meet the electrical load can have a ratio less than the ratio heat-electricity cogeneration producing a surplus of thermal energy. Using the excess heat to power an absorption refrigerator is possible to satisfy a portion of the refrigeration load. Even in this case, reducing the power produced by the cogeneration engine it's possible to meet the electrical, heat and cold loads minimizing the surplus of produced energy. The primary energy can be reduced leading toward zero thermal energy surplus realizing energy savings

The consumption data collected for technological hospital every month serve 525 MWh of thermal power and 310 MWh of electrical power at a ratio heat and power equal to 1.76:1 ratio already exceeds the cogeneration 1.37:1.

Table 1: Values of the efficiencies used in the assessment of energy consumption.

Name	Symbol	Value
Absorption refrigerating system efficiency	EER_{ARS}	0,60
Heat pump efficiency	COP	3.50
CHP heat generation efficiency	η_{CHP_B}	0.47
Heating burner efficiency	η_B	0.90
CHP Electricity generation efficiency	η_{EL}	0.38
Grid Electricity generation efficiency	η_{EL_TR}	0.49

In the summer time using the same energy source of the conventional unit in a cogeneration plant to meet the electrical load there is an overproduction of heat (over 525 MWh per month). The highest demand for electricity (the part that exceeds 310 MWh per month) is bound to summer conditioning.

In the winter using the same energy source of the conventional unit in a cogeneration plant to meet the thermal load there is an overproduction of electricity (over 310 MWh per month). The reduction of primary energy does not prevent the fulfilment of energy needs. Knowing the monthly consumption of diesel and electricity, considering an efficiency of electricity production (domestic) by 42%, it's possible calculate the primary energy required monthly.

The evaluations of the values of PES was made assuming a classic cogeneration system capable of converting into electricity for 38% of primary energy into heat and 48% of the same. After verifying the satisfaction of the thermal energy and electricity needed to operate the hospital as such were evaluated excess energy produced. As evidenced by the data shown in Figure 2, the hospital for proper operation monthly needs 525 MWh of thermal energy and 310 MWh of electricity. In the winter months it has the majority required to provide heat to heat the building, while in summer the majority request concerns the electricity for the production of cold for the summer cooling of the building. The values of the efficiency of the machines used in the installation of cogeneration, complete with heat pump and absorption refrigerators, are shown in Table 1.

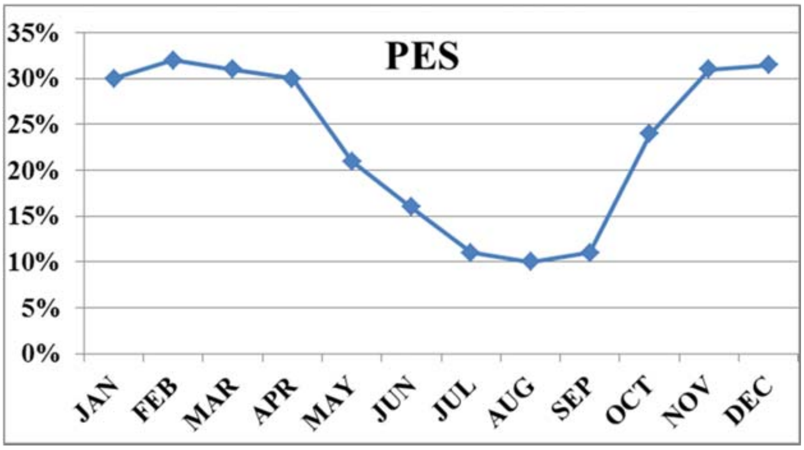

Figure 6: Primary energy savings achievable

In the first case there is a surplus of electrical energy that is converted into heat through the use of a heat pump because of the relatively high value of conversion of electrical energy into thermal energy values of primary energy savings are much higher than the higher the demand for thermal energy with the peak in the month of February.

In the summer months the surplus concerns the thermal energy. A part of this is converted into cold using double-effect absorption refrigerators. Because of the low conversion value, the reduction of primary energy consumption takes values significantly lower than those in winter, reaching the lowest value in the month of August, the hottest month of the year in southern Italy.

Conclusions

The use of a cogeneration system to replace the traditional plant of which you know the monthly consumption of heat and electricity in a hospital in southern Italy has allowed the evaluation of the primary energy savings achievable. Assuming the use of heat pumps and absorption refrigerators has been possible to vary the ratio heat-mechanical power of a cogeneration plant adapting the cogeneration plant to the energy needs of the hospital. Energy saving is verified even in the summer months when it is not dropped below 10%.

In the calculations were assessed excess energy use of which has not been taken into account, but they might find an opportunity to further reduce primary energy consumption by using recovery systems. In the summer months, when the PES reaches the lowest values, it's possible get better results by using photovoltaic panels that produce electricity synchronously with the requirement of the cold.

The possibility of having energy, especially the electric one, even in case of black-out is essential for a hospital that obtains by cogeneration plant the economic savings of purchase of engines for the production of electricity in case of emergency. The availability of self-produced electricity represents a condition of safety for office buildings which make use of a high communications now totally entrusted to the web.

The increasing energy supply in the presence of economic development would avoid loading all the electricity needs on the existing thermal power plants given the enormous difficulties to create new power plants in a densely populated country like Italy.

References

HavelskyÂ V. (1999). Energetic efficiency of cogeneration systems for combined heat, cold and power production, *International Journal of Refrigeration* 22 (pp. 479-485)

Lucas, K. (2000). On the thermodynamics of cogeneration. *International Journal of Thermal Sciences,* 39, (pp. 1039–1046)

Malinowska W., Malinowski L., Green M.A. (2003): Parametric study of exergetic efficiency of a small-scale cogeneration plant incorporating a heat pump, *Applied Thermal Engineering* 23 (pp. 459–472)

DIRECTIVE 2004/8/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC

Verbruggen A. (2008). The merit of cogeneration: Measuring and rewarding performance. *Energy Policy* 36 3059–3066

Kanoglu, M., Dincer I. (2009). Performance assessment of cogeneration plants. *Energy Conversion and Management* 50 (pp. 76–81)