Analysis of the energy efficiency of cold production by trigeneration. Case Study - Hospitality

IOANA DIACONESCU
FIAB, SIM Department
"Dunarea de Jos" University
ROMANIA

Abstract: - There are two reasons why hotels are an important objective from the point of view of trigeneration. The first is the fact that they are aimed at tourism and business, both with a considerable increase in applicants. The second is justified by the fact that energy generally represents, after personnel costs, the largest share in the operating costs of a hotel.

The energy demand of hotels depends on many factors: the category of customers, the type of hotel, the geographical position, the climatic area, the age and condition of the energy consumption systems and, last but not least, the skills – quality – of energy management.

This paper considers the factors presented above and analyses the optimal energy conditions for thermal and cold energy supply of the hotel industry using trigeneration concept.

Key-Words: - trigeneration, hospitality, efficiency, quality, energy management, indoor comfort

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1 General characteristics of trigeneration

The general characteristics of the trigeneration solution refer to two aspects: the production of cold at the CTG (trigeneration plants) and the transport and distribution of the thermal agent used to supply the cold consumers.

The production of cold in CTG is characterized by:

- cogeneration plants (ICG), which produce electricity and heat in cogeneration, used as such also for the production of cold in basic regime, in IFA or IFC;
- cold generation (IF) plants, which can be with absorption (IFA), or mechanical vapor compression (IFC).

In CTG, cold is a by-product of heat (in the case of IFA) or electricity (in the case of IFC) produced in cogeneration by ICG.

Based on cogeneration, trigeneration is the alternative solution to the separate production of heat in CT, electricity in the electromagnetic system (EES) and cold in individual IFCs supplied with electricity also from the EEA, as shown in fig.1 [1].

The advantages of trigeneration over separate production are similar to those that exist in the case of cogeneration. They are based on the favourable effects from a technical, economic and environmental point of view, compared to separate production, as follows:

- increasing the overall energy efficiency of energy production;
- for the same quantities of energy produced, a primary energy saving is achieved;
- by concentrating the production of the three forms of energy and due to the total primary energy savings consumed, compared to separate production, the unit production costs decrease;
- by reducing the consumption of primary energy, direct and indirect pollution of the environment is reduced, with the respective consequences in terms of eco-taxes, of the unit costs of the energy delivered by CTG;
- depending on the degree of centralization/decentralization of the production of the three forms of energy consumption, trigeneration is less restrictive in terms of the type of primary energy used in the CTG;
- depending on the non-simultaneity of heat consumption with those of cold and electricity, the annual classified curve of the energy production of CTG is flattened, which increases the average annual load of the cogeneration plants, increasing their average annual operating efficiency.

The disadvantages of trigeneration, compared to separate production, are mainly determined by:

- depending on the degree of centralization of the production of the three forms of energy, increasing their transport distances, from CTG to consumers. This will decisively influence the cold (coolant) production and transport – distribution system, in terms of the location of the refrigeration installations – IF – and the cold distribution network – RF:
- depending on the degree of centralization of cold production, the heat losses – in the form of cold – of the RF increase.

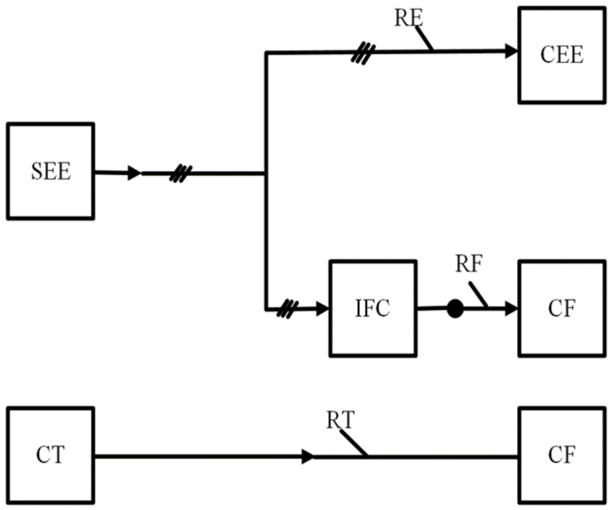

Fig.1 Schematic diagram of separate production of electricity, heat and cold
SEE- the electrical energy system
Where:
CT – thermal control unit
CEE, CF, CC – consumers of electricity, respectively of cold and heat
RE, RT, RF – electrical network respectively thermal and cold (distribution of the coolant for the cold supply.)

Their increase leads to a reduction in the energy efficiency of the entire system consisting of CTG plus the transport and distribution of heat and cold.
The limitations to be taken into account when applying trigeneration are determined by the additional conditioning that has arisen as a result of the three categories of energy consumption, which must be ensured from the same production facilities and possibly the same system of transport and distribution of the thermal agents used for heat and cold supply. Mainly, they are [2]:
- the structure of electricity demands, with those of heat and cold, in terms of quantity and hourly and annual (seasonal) simultaneity;
- the remote transport of cold and then its distribution to consumers requires broader technical solutions and implicitly more expensive than in the case of heat. This limits the degree of centralization of cold production, which leads to the location of FI as close as possible to consumers. The problem is growing as cold consumers do not have the same locations as heat consumers;
- depending on the type of refrigerant used in the FI, additional restrictive problems arise related to environmental pollution and ensuring the safety of consumers against possible emissions from the atmosphere in the form of refrigerant (in the case of ammonia solution);
- the demand for cold for air conditioning of various consumers, even if they are of the same type (households, or tertiary etc.), at the same outdoor climatic conditions, is not the same in terms of the allure of the variation and in terms of momentary size. These differences are determined by the simultaneous effects of factors influencing the size of the heat/cold requirement for air conditioning. As a result, the regulation of the cooling requirement for air conditioning must be customized for each consumer, individually, or on similar groups of consumers, which limits the degree of centralized production of it, or imposes more complex (more expensive) automatic regulation installations.
- The extension of the introduction of air conditioning depends a lot on the value of the bill that the consumer has to pay, i.e. on his financial capacity, which greatly limits the probability of introducing centralized cold supply.

Centralized heat transport and distribution systems (STDC) and cold (STDF)

In certain situations, cold supply systems can be interconnected with heat supply systems, using practically the same transmission and distribution system: this solution can prove to be more economically efficient than using separate systems (SDC and SDF, respectively). Such a system, it must be taken into account, must ensure the two thermal energy demands, either alternately in time or simultaneously, which complicates the problem, from the point of view of the thermal network system, simultaneously with the type of indoor installations used by consumers.

Fig. 2 shows the most used variants for the centralized distribution of heat and cold simultaneously [7].

The two-pipe system – shown in fig. 2.a – is characterized by the existence of two pipes, one for the supply and the other for the return, which operate alternately: in winter, for the heating agent used by the consumer to ensure the necessary heat and in summer, for the cooling agent of the air necessary for cooling.
The main disadvantage of the system is that it does not allow simultaneous supply of heat and cold.

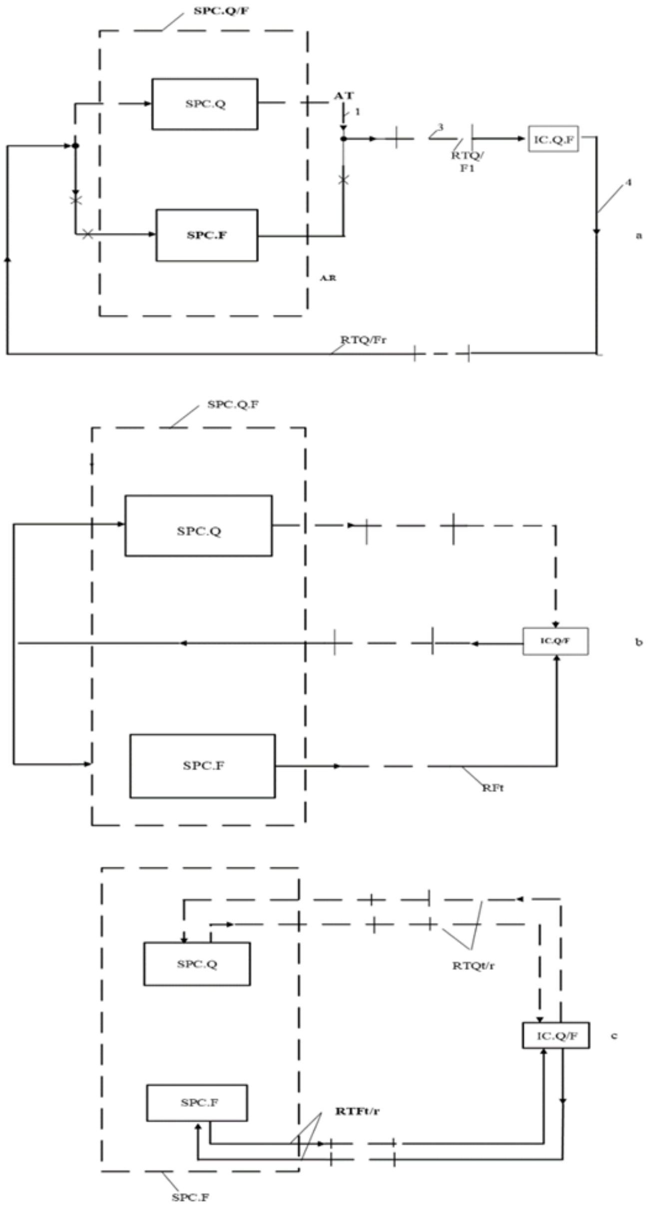

Fig. 2 Schematic variants of the centralized heat transmission and distribution (STDC) and cold (STDF) systems
a - STDQ/F with two pipes; b - Three-pipe STDQ/F, c - Four-pipe STDQ/F: SPCQ/F
Where:
SPCQ - centralized heat production source; SPCF - centralized source of cold production; ICQ/F - heat or cold consuming installations; RTQt, RTQr, RTQt/r - heat transport network: round, return, both for round and back; RFt, RFr, RFt/r - coolant transport network: tour, return, both for tour and return; RTQ/F,t, RTQ/F,r - heat or cold transport network, for the round trip and for the return.

The three-pipe system shown in fig. 2. b assumes that both categories of consumers use the same type of heating agent, for example water. As a result, it is characterized by the existence of a conveyor pipe for the thermal agent (RTt) and for the cooling agent (RFt) respectively and a common one for the return of both thermal agents (RTQ/F r). Here, the disadvantage of scheme 16 disappears. a, on the other hand, the return mixture of the heating agent (G. Q) with the temperature (tr, Q), with the cooling agent (G, F), with the temperature (tr, F) leads to a common return temperature ((tr, Q/F) lower than that imposed by the control chart of the heat consumer ((tr, Q) and higher than that imposed by the cold consumer (tr, F) [3].

The main disadvantage of this system is that it assumes that the thermal agent for the distribution of both heat and cold is water. Also, the energy effects due to the common return of water at a higher temperature than the IF requires and lower than that imposed by the heat source should not be neglected. In addition, compared to the two-pipe version, it certainly leads to additional investments and total production costs, due to the use of three pipes instead of two.

The main advantage of the solution is determined by the fact that it can ensure the simultaneous supply of heat and cold to the two categories of consumers, in the quantitative and qualitative conditions imposed by them, at any time during the summer or winter.

The four-pipe system presented in fig. 2.c is characterized by the fact that each heat/cold source ensures the supply of heat and cold to its own consumers, respectively, through its own two-tube system – round/return – for the distribution of the related heating agent [7].

In general, this system is used in the case of concentrated consumers, who consume both cold and heat simultaneously, such as large commercial complexes, where the transmission and distribution distances are not too long, reducing the negative effect of the increase in the initial investment related to the two pairs of round/return pipes [4].

2 Energy efficiency of trigeneration in the hotel industry

There are two reasons why hotels are an important objective from the point of view of trigeneration. The first is the fact that they are aimed at tourism and business, both with a considerable increase in applicants. The second is justified by the fact that energy generally represents, after personnel costs, the largest share in the operating costs of a hotel.

The hotel sector is characterized by a great diversity in terms of hotel sizes (number and size of rooms), quality (number of stars), occupancy rate, services offered, majority destination (for tourism or business) etc.

In general, at the level of the European Union, the total annual energy consumption in the hotel sector was estimated at approx. 39 TWh. The estimated potential of energy savings achieved by introducing cogeneration/trigeneration is approx. 8 TWh/year, i.e. 20% of the total energy used by hotels.

The energy demand of hotels depends on many factors: the category of customers, the type of hotel, the geographical position, the climatic area, the age and condition of the energy consumption systems and, last but not least, the skills – quality – of energy management.

Due to the diversity of hotels, it is difficult to establish general consumption values. Heating and air conditioning represent on average approx. 48%, the rest of the consumption being for catering (25%), the production of hot water for consumption (13%), lighting (7%) and other services (7%).

2.1 Characteristic of hotel energy consumption

A hotel is a building whose destination aims to offer comfortable rest conditions. However, higher energy consumption does not necessarily mean more comfort. The overall energy efficiency is optimal technical-economic in the conditions of ensuring adequate correlations between increased comfort and related energy consumption, in compliance with the micro and macro climate conditions established by the standards in force [5].

Taking into account all the factors that influence energy consumption, hotels can be classified into the following three categories:

- large hotels, with over 150 rooms, with heating, air conditioning, laundry and indoor swimming pool;
- medium hotels, with 50 - 150 rooms, with heating and air conditioning (in certain areas of the hotel), without auxiliary space services, etc.;
- small hotels, with 4 - 50 rooms (including pensions), with heating and air conditioning (depending on the climatic zone of location and the degree of comfort ensured, the number of stars obtained by classification - without laundry).

Table 1 shows the specific energy consumptions for the three categories of hotels.

Table 1 Total annual specific energy consumption of hotels [kWh/m^2]

Hotel type	Quality of energy management					
	Efficient use		Proper use		Inappropriate use	
	fuel	electricity	fuel	electricity	fuel	electricity
Big	<200	<165	200 -240	165 -200	>240	>200
Medium	<190	<70	190 -230	70- 90	>230	>90
Small	<180	< 60	180 -210	60-80	>210	>80

2.1.1 Energy consumption for space heating and air conditioning

The consumption to satisfy the comfort conditions is very different from one hotel to another, depending primarily on the climatic zone in which it is located, the size of the temperature difference in winter - summer, the type of heating system, respectively air conditioning and the quality of the thermal insulation of the respective building, as shown in table 2.

Table 2 Specific indoor comfort conditions for winter/summer

The type of provided comfort	Destination of the spaces	Recommended indoor temperatures (°C)
Normal heating	Occupied	20-22
Low-temperature heating	Unoccupied during certain periods	16-18
Heating in stand-by	Unoccupied for long periods	12-14
Minimum heating regime	Unoccupied in winter	7-8
Cooling	Common areas and rooms, during the summer	5°C under t_{ext}
Cooling	Common areas and rooms, during the winter	23

2.1.2 Energy consumption for hot water preparation

The demand for hot water in hotels generally varies greatly depending on the class of the hotel (number of stars). Thus, for a 5-star hotel, this consumption is approx. 150 l/day.customer, while in a 3-star hotel it reaches approx. 90 l/day.customer.

The hot water is primarily intended for the showers/baths in the rooms, the hotel kitchen and various other auxiliary services. For hotels that have restaurants, kitchens and laundries, the energy consumed for the production of hot water is approx. 1500-2300 kWh/year.room.

In terms of the systems adopted for the production of hot water, they can be accumulated, instantaneous, or mixed. Hot water is usually accumulated at 60°C (and distributed in rooms) at 45°C. It can be produced with the help of electricity, natural gas, fuel oil, solar energy or from the recovery of heat produced by burning waste.

2.1.3 Energy consumption for lighting

Hotel lighting installations must ensure the lighting levels required by the nature of the activity, while creating a pleasant environment and a feeling of comfort. Depending on the class of the hotel, the consumption for lighting can represent between 7 and 40% of its total electricity consumption.

The lighting levels required for each area of the hotel are established by specific regulations.

For example, the installed power is approx. 10-20 W/m2 for rooms and 15-30 W/m^2 for common areas, leading to an annual specific consumption of 25-55 kWh/year

2.1.4 Energy consumption for catering-kitchens

In the kitchens, the activities with the highest specific energy consumption are carried out in hotels. It depends on the number of places for dining and the daily number of meals served, as well as the way of preparation. It is appreciated that the kitchens correspond to approx. 25% of the total energy consumption of a hotel. Of this, most of it (60-70%) is needed for cooking installations. It is worth noting that there is an important basic demand during the night and in the early hours of the morning, necessary for the refrigeration of food.

Most often, the source of energy for cooking is natural gas, but also electricity.

The average annual specific energy consumption of kitchens is approx. 1 - 2 kWh/year.meal. In addition, the following energy consumption is estimated:

- 4.5 l/meal of domestic hot water, at 60°C, plus hot water for washing dishes, totaling approx. 0.2 - 0.3 kWh/year.meal;
- 0.1 - 0.3 kWh/year.meal for food preservation, for preparation;
- the electricity consumed for the ventilation of kitchens represents an important contribution, in relation to the total consumption. The size of the respective consumption depends on the electrical power installed in the fan drive motors and the annual duration of the actual operation of the kitchen.

2.1.5 Energy consumption for laundries

The basic destinations of energy consumption for laundries are: heat/energy for hot water preparation, drying, ironing facilities and possibly heat in the form of steam for sterilization.

The average specific energy consumption is approx. 2 - 3 kWh/year.kg of laundry.

In general, laundries use steam at 110 - 120°C.

It is worth noting that the annual degree of energy use remains constant, regardless of the degree of occupancy; This means that certain equipment and lighting work daily during the same periods. An adequate planning of the hourly-daily operating regime of the laundries can significantly reduce the peak of daily energy consumption of the hotel complex. It is also noted that indoor pools use approx. 45-75 MWh/season.

2.1.6 Total annual specific energy consumption

The specific annual consumption of a hotel is mainly influenced by the number of rooms, as shown in fig. 3. Compared to this, it can be said that hotels with a specific total annual energy consumption, which is below the line in the diagram, are those with good energy management. The others, with a higher specific consumption, first require the application of measures to reduce them and only then will the efficiency of the trigeneration solution be established.

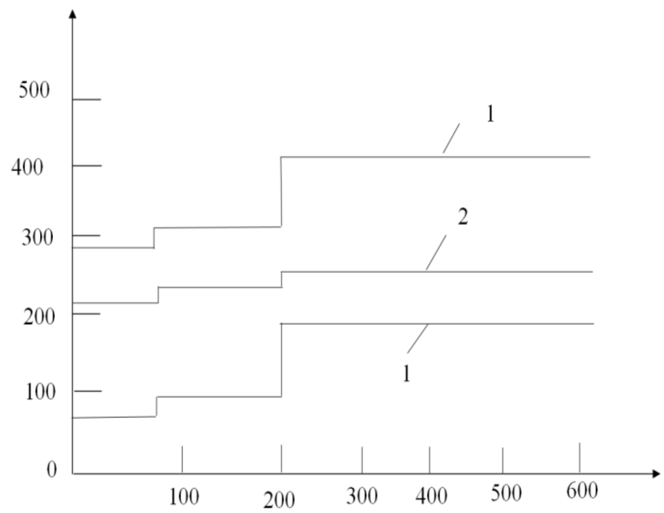

Fig. 3 Dependence of the limit value of the annual specific energy consumption of hotels, on the number of rooms, for the consumption of: 1 - electricity 2 - heat 3 - total

2.2 Investments in trigeneration plants

According to the above, investments in a CTG consist mainly of those related to:

Table 3 Specific investment in steam CRAS for supplying IFA

Characteristic values		U.M.	Nominal cold flow rate of IFA			
			1 MW_f		1,4MW_f	
1		2	3		4	
Flue gas outlet temperature from MAI		°C	260	(1)	212	(1)
					138	(2)
Steam flow rate at the parameters	9 bar,175°C(1)	t/h	1,4	(1)	2,0	(1)
	2,5bar, 130°C(2)		2,4	(2)	3,0	(2)
Specific invest, i_{CRAS}		€/kg	90	(1)	67,5	(1)
			54,6	(2)	49,3	(2)

(a) the cogeneration system, which includes the ICG itself, the electric generator and their additional equipment;

(b)the system that ensures the taking of heat from the ICG and its delivery in the form of the heating agent, at the parameters imposed by the consumers; in the case of the "open" ICG, this system is represented by the heat recovery system, which at the limit can be considered part of the ICG, as well as the electric generator;

(c) cooling systems – with IFA absorption and/or compression (IFC);

(d) the cooling system of the IF, consisting of the cooling tower and the associated building exchanger;

(e) peak thermal installation (ITV) and reserve, in the form of a boiler, generally of hot water (CAF).

The initial costs of the GCC depend on the type and size of the GCC, the complexity of the CMA systems, the need for special equipment to reduce/avoid air and noise pollution, for the preparation of the site, the connection to the utility networks (water, fuel – CH4, electricity) and for the set of electrical installations that ensure the takeover of the electricity produced and its delivery to the EEA.

In practice, the total installation costs of the GCC vary considerably. The MIA producers deliver these installations with specific investments of even below 800 €/kWe, for CCG with installed electrical powers > 500 kWe reaching up to 1300 €/k, in the case of ICG with < 500 kWe. When the CCG also uses a CH4 CAF, those values can reach €1700/kWe. In the case of CCG with gas turbines, the total specific investment can reach 1600...2000 €/k. The graph in Fig. 4 presents – informatively – the dependence of the specific investment in the GCC as a whole, on the installed electrical power (ICCG = f (PnCCG)), for equipping with MIA or gas turbines, results for GCC projects carried out.

The initial costs of the heat recovery system (SCR) include the respective values for: the additional combustion recovery boiler (CRAS), the supply water tank, the related pumps and the control panel. From experience, for the steam producing CRAS (for IFA), the specific investment is:

= 36...95 €/kg.steam, on average being 59 €/kg.steam, as shown in Table 3.

The initial costs of absorption cooling systems (IFA), with BrLi - water solution, for a two-stage unit are approx. 20-40% larger than one with one stage, hence the capacity (due to the generator and the additional capacitor). Also, a hot water API is approx. 25% more expensive than a similar steam one, hence the capacity (the connection pipes necessary to supply the necessary fall to the system by absorption are of larger diameters at IFA with

hot water, compared to those with steam). However, there are different opinions, depending on the API manufacturer, according to which a two-stage API is 5-8% cheaper than a one-stage one, operating on hot water "at low temperature" [6].
Fig. 5 shows the indicative values of the specific investment for CRAS, depending on the nominal cooling flow rate Qn of the IFA [kW_f].

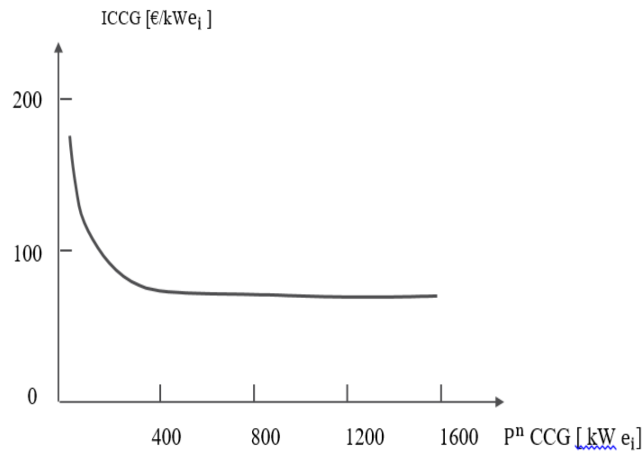

Fig. 4 Dependence of the specific investment of a CCG, on the installed electrical power, for ICG of the MIA type or gas turbines (does not include the share related to the CH4 supply) [7].

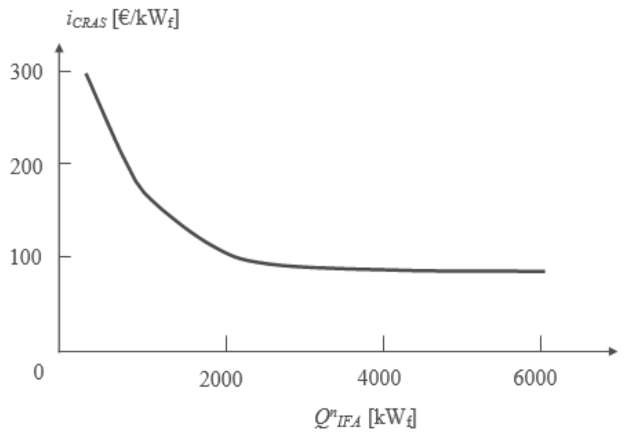

Fig.5 Variation of the specific investment in the API cooling system, with BrLi - water solution, depending on the nominal cold flow rate produced by the IFA

3. Conclusion

EFEN.CTG dependency analysis of the main factors leads to the following findings:

-One of the main factors influencing EFEN. CTG, is represented by the reference cogeneration index, as shown in fig. 6.

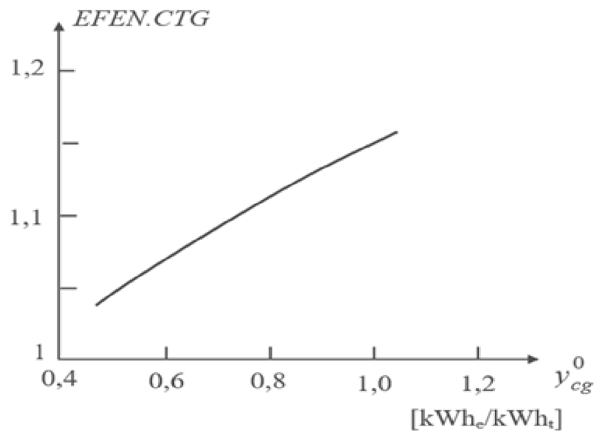

Fig.6 EFEN.CTG dependency of the reference cogeneration index y_{cg}^o

It is noted that EFEN. CTG increases significantly with increase of y_{cg}^o.
- Effects of heat production efficiencies in peak installations ITV, in IFA.V ($\eta_{B.IFA.V}$) and respectivelly in IFC.V (η_{SEE}) are shown in fig. 7.

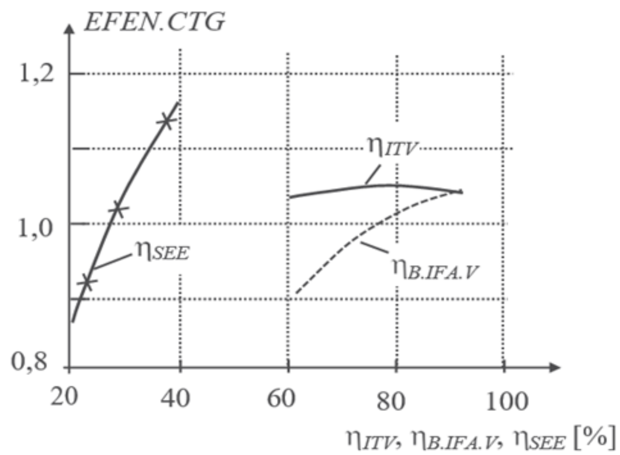

Fig.7 EFEN.CTG dependency of ITV, IFA and SEE efficiencies

It is found that η_{SEE} has the highest influence on EFEN.CTG, followed by $\eta_{B.IFA.V}$ influence andalmost insignificantly by η_{ITV} and EFEN.CTG increases with the size of this yields [7].
- EFEN.CTG is not influenced by the energy efficinecy of the IFA.B, mening that it does not depend on $COP_{IFA.B}$, which uses the heat produced in cogeneration by ICG.

- On the other hand, EFEN. CTG increases with the reduction of energy consumption for IFC. B and IFC.V, through the $COP_{IFC.B}$, $COP_{IFC.V}$ respectively $COP_{IFA.V}$ as shown in fig 8.

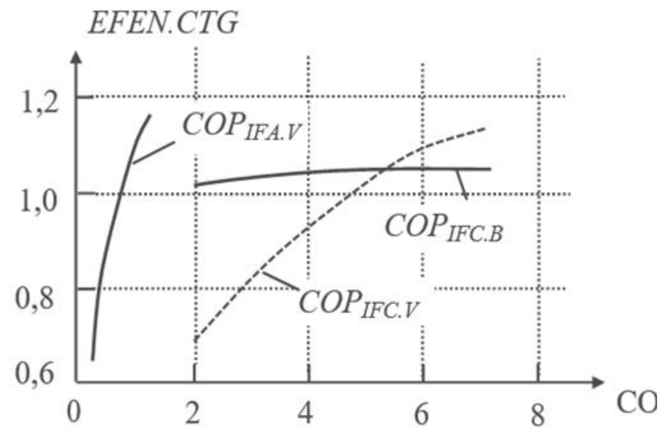

Fig.8 Variation of EFEN.CGT with COP

It is noted that EFEN. CTG increases with the increase in COP: COP is most influenced by the lowest values, which correspond to the $COP_{IFA.V}$, followed by the influence of $COP_{IFC.V}$ and very little influenced by $COP_{IFC.B}$.

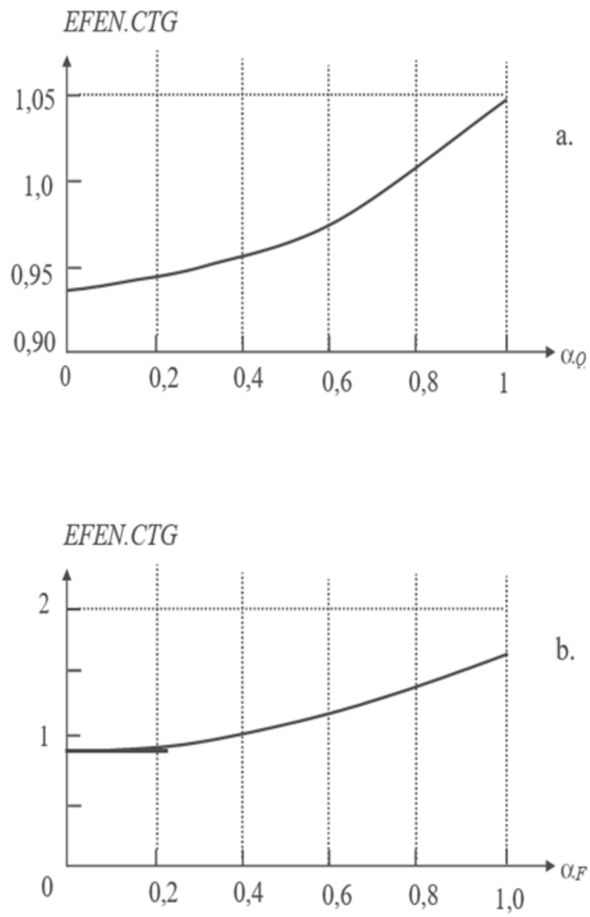

Fig.9 Dependency of EFEN.CTG by the heat production value

So, EFEN. CTG is growing especially with the increase in energy efficiency of IFCs used as cold production plants in peak consumption regimes; the effects of the influence are amplified as the COP value is lower.

- EFEN. CTG α_Q increases, almost linearly, with the increase of the trigeneration coefficient for heat (α_F) as shown in fig 9.

-EFEN. CTG increases as the shares of heat consumption γ_Q and cold γ_F increase in the total energy consumption delivered by CTG (E + Q + F) as shown in fig 10.

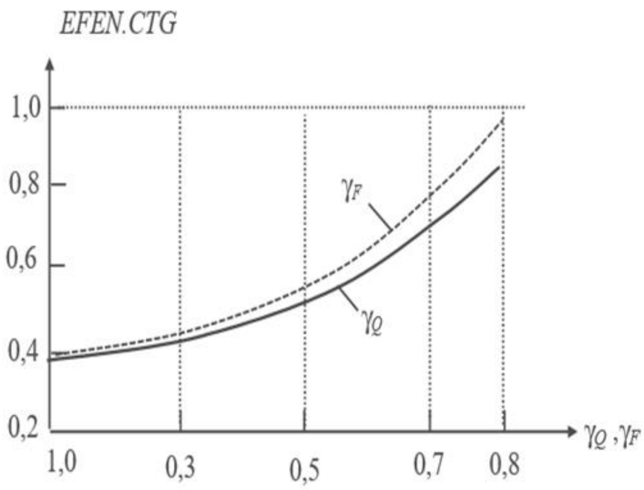

Fig.10 EFEN.CTG dependency of the share of heat and cold production in the total energy delivered from CTG (E+Q+F)

The conclusion is that in order to achieve the highest possible overall energy efficiency, it is necessary that the energy production efficiencies in the CTG contour in the SEE and the performance coefficients of peak refrigeration installations are as high as possible.

The production of cold in basic refrigeration installations is recommended to be done using IFA, which thus increases the cogeneration coefficient of heat α_Q; the production of cold in peak mode is recommended to be done using IFC.

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