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STUDY ABOUT THE POSSIBILITY OF USE MICRO-CHP SYSTEMS AT HOME

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ABSTRACT

This work is made with the goal of analyse the possibility of introduce the micro-CHP (Combined Heat and Power) systems for the distribution on electric and thermal energy in a building of 25 apartments. The work studies 3 different systems of cogeneration:

- Internal Combustion Engine (ICE)
- Micro Gas Turbine (MGT)
- Stirling

All of these systems are available in the market. Each system of generation is composed of one Prime Move (PM), a thermal energy storage unit and an auxiliary boiler used to cover peak thermal demands.

For made this study we are based in cover the demand of a building of 25 apartments, all of the with the same surface and the same characteristics. At the end of this paper we could decide which of these technologies is the most developed, as well as the technology that needs more time to be developed.

Usually, the introduction of these systems of cogeneration make reduce the energy taken of the grid more of 20%, and improving the feasibility of the engine.

1. INTRODUCTION

The cogenerations systems are already being utilized for cover the peak values of the thermic and electric demand in those systems whose timetables of consume are predictable. In a becoming and for this reason it was used in the industrial sector. But in last years exist the tendency a introduce in buildings and apartments for cover the demand of the residential sector. The interest of use systems of cogeneration starts at 80s decade, and was proved that they can improve the site energy fuel consumption by the reduction of prime energy consumed.

Problems of contamination, economy or legislative have made that the use of cogenerative systems have improved, especially when the electric demand for cover not is so high. This is because these engines don’t have already good characteristics of efficiency and low price that has the usual boilers.

The objective of this work is study the capacity of these modern systems like a real alternative in front of the usual boilers of our homes. The three systems that we are going to study are based in two “mature” technologies that are the ICE and MGT, and in a one technology more new like Stirling Engine. This job is based in the characteristics of an engine for a micro CHP system that are already in stock at the market. For make fine the work I have obtained first of all the graphics of electric and thermal power demands, over an average day at each season of the year: Summer, Winter and intermediate (Autumn and Spring).

The three systems that we are going to study of micro cogeneration are based in three parts:

_ A Prime Mover (PM) that is different in each type of engine and it is characterized in that it is electric power is over 3 kW

_ Optionally, could be an accumulate of thermal energy. We are going to study with or without it, and his function is accumulate energy for spend it at the peak hours.

_ Finally we have an auxiliary boiler for be sure that the distribution of energy is save, specially to cover the demand at the peak hours when the energy accumulation cannot cover all this demand.

The energy improve, in terms of prime energy saved for each CHP are evaluated.

2. ENERGETIC REQUIREMENTS FOR BUILDINGS

2.1 THERMAL ENERGY DEMANDED

The requirements of the demanded thermic energy for residential buildings are described in “EPBD”. This establishes the basic principles of the demanded thermal energy. Also it gives us an idea of the requirements needed according to the European legislation, and report the value of the energy limits (ephw). These limits are related with the thermal power, as well as the values of the performance and efficiency of the production and distribution of the heat. The range of energy goes from 10 to 300 KWh/m2*year.

2.2 ELECTRIC ENERGY DEMANDED

The demand of electric energy in Europe has several reports, with the tendencies of the electric demand in residential buildings in the continent. Besides it can also be noticed the range of electric consumption in average households.

3. TECHNOLOGIES USED

Analysis of the three cogeneration systems studied and previously named.

3.1 INTERNAL COMBUSTION ENGINES [1]

Internal Combustion (IC) engines are similar to vehicle engines modified to run on natural gas or compression-ignition diesel. These systems primarily use spark-ignition engines to provide the motive power. They offer mid-range performance of 20-40% electrical efficiency, but 1kW domestic models can only operate at a fixed output rather than following the demand of the property. The heat produced is usually hot water, rather than steam, and they generally produce 1 to 2 units of heat for each unit of electricity, with the ratio of heat to power generally decreasing with size.

These mCHP systems are best suited for smaller sites where the demand for electricity is reduced and the requirement for heat and hot water is high.

3.2 MICRO TURBINE GAS [1]

Natural gas is suitable for internal combustion engines, such as Otto engine and gas turbine systems. Gas turbines are used in many small systems due to their high efficiency, small size, clean combustion, durability and low maintenance requirements. Gas turbines designed with foil bearings and air-cooling operates without lubricating oil or coolants. The waste heat of gas turbines is mostly in the exhaust, whereas the waste heat of reciprocating internal combustion engines is split between the exhaust and cooling system.

3.3 STIRLING [2]

The most novel application in micro cogeneration is the Stirling Engines.

The main key is the use of a free piston Stirling engine. Within the engine there is an inert fluid, helium in most cases that heats and cools indirectly and alternatively by the gas circuit of combustion and the return after heating the ACS.

Due to the heating and the cooling, the piston performs an ascendant and descendent movement that combined with a magnetic field produces electric current. The Stirling engine only produces electric energy instantly when there is a demand of heat, which is the end of the cogeneration.

4. METHODOLOGY AND HYPOTHESES

First of all I am going to explain the 5 fundamental hypotheses to understand the project: [1]

- The PM is operated in an ON/OFF mode, without load modulation and thermal energy dissipation, so that the PM has to meet the thermal demand through a thermal load following operating mode, while the produced electricity is a secondary product, depending on the specific electric-to-thermal power ratio

- Since the PM is operated without thermal energy dissipation, all the recovered heat on an hourly basis is supplied to the utilities or accumulated in the TES unit. If the produced thermal energy is larger than the sum of the residual TES capacity and of the thermal demand on an hourly basis, the PM is switched OFF.

-The control logic of the PM is aimed to maximize the profitability. For this reason, the PM is preferentially switched ON during the so-called ‘‘peak hours’’, i.e. when the revenue for electric energy production is the highest

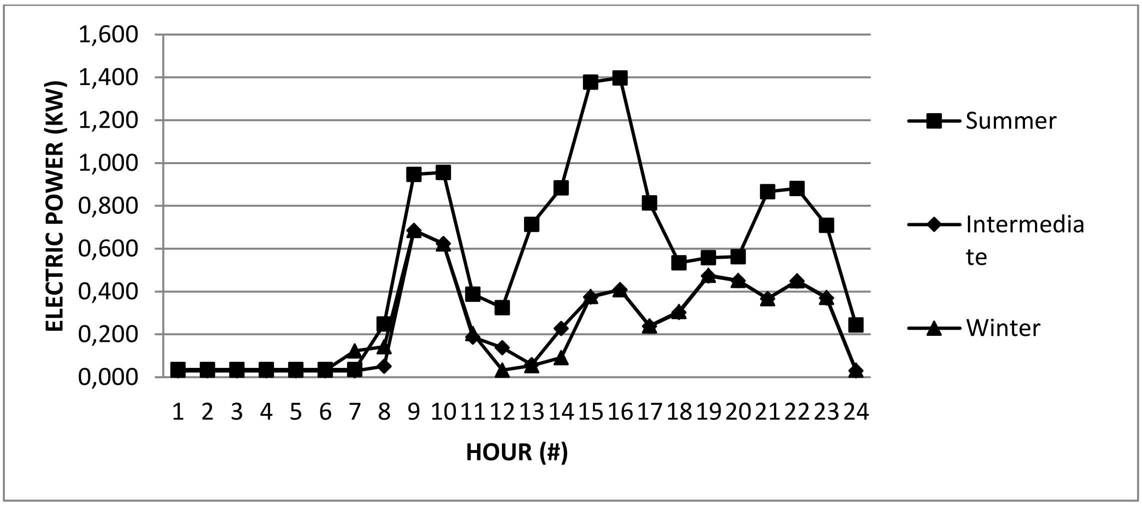
-An auxiliary boiler, which is part of the whole CHP system, is used to meet peak thermal demands, when both the PM I in CHP configuration and the TES unit cannot meet the thermal demand on an hourly basis.

-The electricity distribution grid acts as a storage system for electric energy: excess electricity produced by the PM, and not self-consumed by the user, is sent to the grid, while the electricity is taken from the grid when demand is greater than consumption.

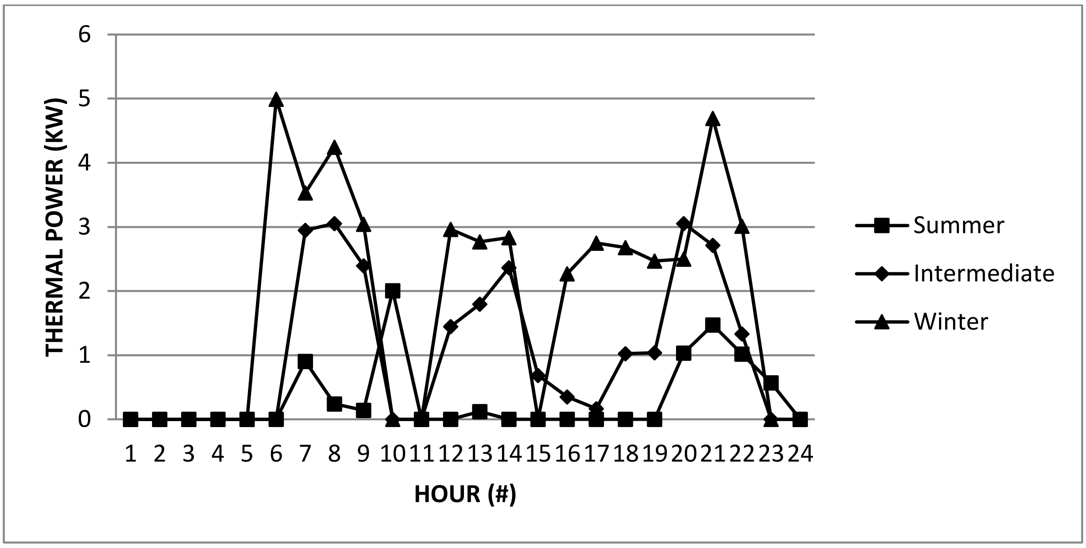
5 ENERGY ANALYSES

5.1 APARTMENTS [3]

The study is designed for a building with 25 apartments, all of them with the same surface and with the same characteristics. Based on the values of thermal and electric energy consumed we can plot two graphics of consume (electrical and thermal) for the 24 hours of a day, having in mind that we have to consider the different seasons. These are the graphics of consume for each individual household:



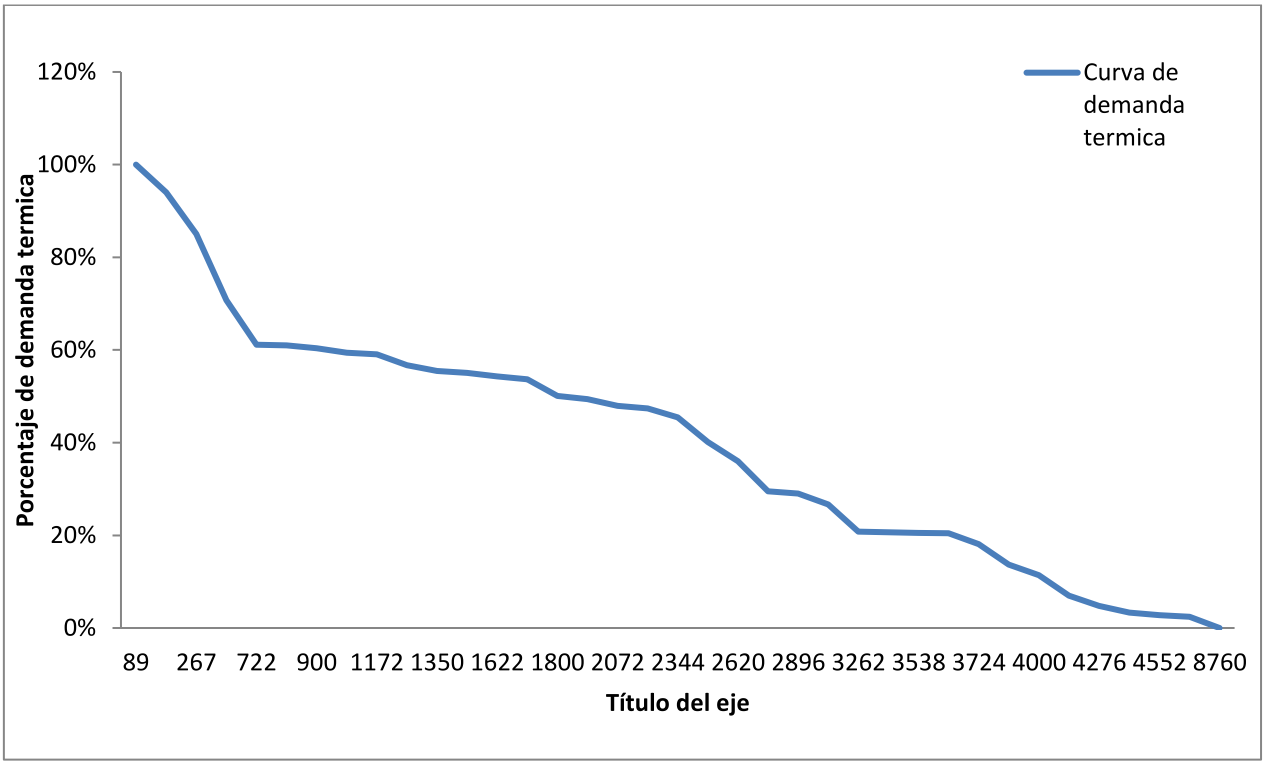
** Electric consume



** Thermal Consume

Continuing with the energetic analysis, it is needed to know the value of the power we are expecting in order to select the most convenient machines in the market. For this task we are going to use the maximum power rectangle study [4] [2], based on the thermal demand accumulated through the year to be able to study the value of the action power of our micro CHP system. The thermal demand is used by agreement, instead of the electric, due to the fact that the value of the thermal power generated in the machine is going to be larger than the value of the electric power.

Once we have obtained the accumulated demand plot we should calculate the maximum rectangle area existing, having in mind that the bases of the rectangle are located in the abscissa and ordinate axis, and that the opposite vertex is on the demanded function curve. With the data obtained from the previous graphics of electric and thermal consume we can obtain the following plot:



From this graphic is deduced that the value of the maximum rectangle is located within the 3694 hours with a percentage of 53%. This implies that the power needed to supply for each apartment is 1.556 KW. Therefore it is needed a machine of each type that can reach approximately 60 KW of thermal power.

5.2 ENGINES

Knowing the value of the thermal power needed in the machine, we perform the research of what micro CHP machine available in the market we can make use from. For the case of ICE and MGT it is relatively easy to find a machine of each kind that can work with this characteristics, but in the case of the Stirling engine and due to the limited maturity, it is needed the configuration of two machines of the same specifications working in parallel. The machines chosen and some their features are the following:

	Empresa	Pe	Pt	Pin	ηe	ηt	ηchp	Cchp	refs
MGT	Capstone C30	30	61	114.7	26,2	53,2	79,3	0,492	[5]
ICE	Yanmar CP35D1	35	59,8	107,7	32,5	55,52	88,02	0,585	[6]
Stirling	Qnergy	13	72.8	88	14,77	82,73	97,5	0.178	[7]

It can be noticed, base with the values provided, that the ratio of the micro CHP between the electric and thermal power are similar to the ICE and the MTG, close to 0.5, but in the case of the Stirling engines this ratio is reduced to 0.178, owing to the fact that it is generated much more thermal energy than electric, obviously caused by the less development of this technology.

5.3 PRIMARY ENERGY SAVING [1]

This way we can study the amount of primary energy not spent due to the micro cogeneration systems, and comes defined by the equation:

$$PES = 1 - \frac{E_f}{\frac{E_e}{\eta_{es}} + \frac{E_t}{\eta_{ts}}}$$

Being E_e and E_t the electric and thermal energy produced respectively, and E_f is the energy from the fuel feeding the PM with the CHP configuration. Finally η_{es} and η_{ts} are the reference values of the efficiency for the production division of electricity and heat respectively.

5.4 THERMAL ENERGY STORAGE UNIT [1]

To be able to design the TES according to the right dimensions we have to consider the temperature variation between the fluid and the input and output sections of the TES. This temperature variation will be fixed on 30 ºC. Once we know this we can calculate the volume of the TES:

$$V = \frac{(P_{tH,W})_{max}\, h_{stor}}{\rho c \Delta T}$$

C=4.18$\frac{kJ}{K*kg}$; ρ=1000 $\frac{kg}{m^3}$;

6. RESULTS

Finally we are going to perform the final analysis of the paper, with the study of each machine separately. From each machine we are going to do tow analysis, the first one as our cogenerative system has not an energy storage system and the second one as if it would have it, with the ideal volume value of it.

A thermal energy storage system has the function of save the extra energy generated in the valley hours, so we can use it after in the peak hours, when our micro CHP system will not be able to satisfy the thermal power demand by itself. With the values of Table 1 we are going to get the power of each machine on each apartment:

$$P = \frac{Pot. de\ la\ maquina}{25\ apartamentos}$$

Once we have the power of each type of machine we will analyze the amount of hours it has to be working, which will be when the demanded power is higher than the working power, this way we will know the time each machine will be working:

$$P_{MGT} = 2.44\text{ KW}$$

$$P_{ICE} = 2.39\text{ KW}$$

$$P_{STIRLING} = 2.91\text{ kW}$$

From this, we will analyse each machine separately, starting with the MGT (Capstone C30):

6.1 MGT [5]

Based on the characteristics of TABLE 1 we will start with the energy study of the machine with and without the energy storage system, finally we will compare both values.

6.1.1 Without energy storage system

First of all we have to consider that the thermal power demanded by the buildings in a year is 228494.35 KWh, while the electric power is 67746.02

kWh. Being this values the sum of the power for a year for the whole building. The values are going to be the same in each type of machine, because is the power or energy demanded by the building.

Secondly, we are going to study the amount of hours the machine will work, which will depend on the season. We obtain that in winter the machine should work 13.93 hours per day, in Autumn and Spring it will be reduce to 9.16 and finally in summer only 3.08 hours per day. This way we can know the thermal and electric energy generated by the machine. TABLE 2

Finally we are going to analyze the electric energy we need to exchange with the net, and also the use of an exterior boiler for the thermal energy. This is due to the fact that with my micro CHP system I cannot serve all the demand during the peak hours. In the case of the electric energy it is annually needed -33997.30 kWh, also it can be selled to the net an amount of 62459.77 kWh. While in the case of the thermal it is going to be necessary an auxiliary boiler that can provide a total of 33143.30 kWh to ensure the energy distribution.

6.1.2 With energy storage system

For the second part of the analysis of the MGT we are going to study what would happen if we had the chance of storage the extra thermal charge of the system so we can use it later when the demanded power is higher than the generated. The demanded energy by the building is the same than before, nevertheless now the machine is going to work a larger number of hours per day, which will generate more power.

As done before, knowing the amount of hours worked by the machine daily we can obtain the total number of hours worked in a year, as well as the energy generated in that period and the exchanges with the net. All this values are shown in TABLE 2:

	Without energy storage system	With energy storage system
H for day in Winter	13.93	18.34
H for day in intermediate	9.16	9.99
H for day in Summer	3.08	3.08
H at year	3202.49	3746.87
Thermal energy generated in one year (kWh)	195351,05	228568,47
Electric energy generated in one year (kWh)	96074,29	112410,72
Thermal energy autoconsumed (kWh)	195351,05	228494,35
Electric energy autoconsumed (kWh)	46892,32	46892,31667
Thermal energy from the auxiliary boil or TES (kWh)	33143,30	38512,23
Thermal energy inutilizated (kWh)	0	38646,41
Electric energy from the grid (kWh)	33997,30	33637,59
Electric energy to the grid (kWh)	62459,77	78302,30

It can be seen that the thermal power generated with the energy storage turn out to be very effective, because the amount of energy generated and consumed are practically the same, besides it covers the total thermal demand of the previous exercise. Although we have to consider the energy exchange balance of the machine too. There will be moments when we will need the storage system to help, but also moments when we will have an extra energy that we will keep storing.

6.2 ICE

The analysis of this second machine is exactly the same than the previous one, but considering the values of TABLE 1 for the ICE. Hence the explanation between the difference the thermal storage and the lack of it is not needed and we can show the table with the interest values for further analysis:

	Without energy storage system	With energy storage system
H for day in Winter	13.95	18.71
H for day in intermediate	9.27	10.19
H for day in Summer	3.14	3.14
H at year	3228.96	3820,87
Thermal energy generated in one year (kWh)	193079,68	228488,13
Electric energy generated in one year (kWh)	113006,50	133730,51
Thermal energy autoconsumed (kWh)	193079,68	228488,13
Electric energy autoconsumed (kWh)	48523,04	48523,04
Thermal energy from the auxiliary boil or TES (kWh)	35414,68	40736,88
Thermal energy inutilizated (kWh)	0	40730,65
Electric energy from the grid (kWh)	32829,10	31110,19
Electric energy to the grid (kWh)	78089,59	97743,24

Similarly than before, the solution with the thermal storage is pretty convenient, this way the CHP system will work more hours, storing the extra thermal energy to use it later, making the total thermal energy generated by the boiler in a year the same than the thermal energy demanded by the building; while in the case we do not use the storage system the generated energy will be inferior than the demanded making the use of an auxiliary boiler mandatory. I would also add than the electric energy generated is higher than the demanded by the building, making the energetic balance positive.

6.3 Stirling

Same procedure as before, we have to consider the values of TABLE 2, this way we will be able to perform the calculations needed previous to the comparative table between the use or nonuse of the thermal energy storage system:

	Without energy storage system	With energy storage system
H for day in Winter	13.27	18.34
H for day in intermediate	8.26	9.99
H for day in Summer	2.58	3.08
H at year	2931.93	3746.87
Thermal energy generated in one year (kWh)	213444,38	228531,02
Electric energy generated in one year (kWh)	38115,07	40809,11
Thermal energy autoconsumed (kWh)	213444,37	228491,24
Electric energy autoconsumed (kWh)	35289,26	35550,95
Thermal energy from the auxiliary boil or TES (kWh)	15049,98	30981,42
Thermal energy inutilizated (kWh)	0	31018,09
Electric energy from the grid (kWh)	45052,86	45971,51
Electric energy to the grid (kWh)	15421,91	19034,61

As we can imagine due to the ratio between the thermal and electrical energy, this machine generates a superior amount of thermal power than the other previous machines, nevertheless it is not sufficient in terms of the generation of electric energy. Like the other two machines it is really profitable the use of the thermal energy storage system, which will allow the system to generate a thermal power equal to the thermal power demanded by the building. On the contrary it will be necessary the use of an external boiler to supply the system during de demand peaks.

6.4 AUXILIARY BOILER POWER

With the goal of giver thermic energy without interruptions it must be necessary have an auxiliar boiler, wich will work in the peak hours and will be different for each engine an for calcule it we are going to use the moment when there is more difference between the power of my engine and the maximum demand of thermal power:

ENGINE	Maximum demand of power (kW)	Power of the engine (kW)	Power of the auxiliary boiler (kW)
MGT	124,83	61	63.3
ICE	124,83	59.8	64.5
Stirling	124,83	72.8	51.5

6.5 VOLUME OF THE THERMAL ENERGY STORAGE UNIT

In the same way that we need to know the power that is suministrated by the auxiliary boiler, when there is energy storage unit we should know the volume of this accumulator with the formulation explained in the point 5.4:

Engine	TES VOLUME (m^3)
MGT	0.486
ICE	0.477
Stirling	0.581

6.6 PES OF EACH MACHINE

To continue with this analyse we need calcule the PES, and as the same way of the TES, we only need to calculi the ecuation explained in the point 5.3. The values of the variables have been explained in the tables, and the parameters are in the reference [1]:

ENGINE	PES
MGT	0.225
ICE	0.321
Stirling	0.275

For calcule the values of the PES I have used the case of don't use Thermal Energy Storage unit, with the electric and termal energy that are produced in one year, and with the input power of the engine. Always thinking in the hours that works in one year.

6.7 FINAL ANALYSIS

To summarize, we can observe clearly by the data of each machine that the MGT and ICE have very similar features in terms of generated energy, thermal or electric. Otherwise in the Stirling machine there are a big difference, mainly in the generated energy, it is reduced severely due to the low ratio of the machine.

Also we should mention the idea of the thermal energy storage system, which will allow us to avoid missing the extra energy, resulting in a very energy-efficient system. This way the machines are going to work just the hours needed to generate a thermal power equal as the demanded. This will decrease the need of a supplement of extra thermal energy. In the case of the electric energy, as the system is connected also to the net it is going to be possible the exchanges of energy in both ways, making possible to sell this energy during the valley hours, so the exchange balance will be positive in the case of ICE and MGT but will be reduced in the case of the Stirling machine.

Similarly, it is understandable that the working hours of the machine will increase considerably when we make use of the energy storage system, because the energy can be generated and saved for its late use, compensating this way the valley hours with the peak hours. This way we will make the value of the thermal energy generated similar to the thermal energy demanded.

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