

HIGH EFFICIENCY POLYGENERATION APPLICATIONS (HEGEL)^{i,ii}

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ABSTRACT

The European project high efficiency polygeneration applications (hereinafter HEGEL) financed by European commission in the 6th Framework Programme under priority 6.1 is aimed at develop, demonstrate and compare high efficiency applications of micro-polygenerationⁱⁱⁱ for the civil and industrial sectors, based on innovative technologies.

The project leaded by FIAT Research Centre involves 11 partners from 6 countries, of which 5 Member States (Italy, France, Sweden, Spain, Belgium) and 1 Candidate Country (Turkey). Three demonstration plants will be constructed and tested:

“ICE-Desiccant” application (hereinafter ICED), a tri-generation plant that will be installed in Torino (Italy) in a series lecture halls.

The plant capacity will be 120 electrical, 186 kW heating, , 212 kW of cooling (external air @ 28.8°C 68% R.H)

- A “Combi System” application (hereinafter CS). The Combi System is constituted by two integrated cogenerators powered by different prime movers: an innovative reciprocating engine cogenerator and a Rankine engine system (bottoming cycle) operated on the exhaust gases of the reciprocating engine. Such plant will be installed and test in Turkey at

- Middle Technical University. The plant capacity will be 145 electrical and 166 kW heating
- “MT-Absorption” application (hereinafter MTA), a trigeneration plant that will be installed in Spain to perform the energy service to an office building. This application foresees the integration of a microturbine cogenerator with an ammonia-water absorption cycle.

During the project these the performance of the three plants will be compared.

1. INTRODUCTION

The recently published action plan for energy efficiency^{iv} underlines that the European Union is facing a crucial challenge in the energy field.

In spite of this, Europe continues to waste at least 20% of its energy due to inefficiency and the perspectives for the future is that in 2050 is that almost three quarters of the world's energy supply will still come from fossil fuels and energy demand as well as CO₂ emissions will more than double^v.

In this scenario one of the most important of EU objectives is to lead the way in reducing energy inefficiency, using all available policy tools at all different levels of government and society.

Unfortunately policy measures will not be enough and research should play a key in developing new options for limiting CO₂ emissions in a cost effective way and improving the efficiency of existing energy technologies.

The diffusion of ecological, distributed, small scale power generation technologies, combined with the implementation of more effective measures for higher efficiency on the demand side (listed among the key technologies in all energetic scenarios at European and at global level) will contribute to achieve the above objective.

The model (suggested by EU smart grids platform) is to complement centralised power generation with distributed RES and polygeneration systems .

Due to their substantial first principle efficiency, they offer the additional advantage of significantly improving end use efficiency when either heating or cooling.

The result is overall system efficiency and lower CO₂ emissions with respect to the conventional service for the same power outputs to the user, as detailed below:

In this framework HEGEL will test on the field the some of the most promising technologies for distributed generation without overlooking market and competitiveness aspects.

In the frame of the project three demonstration plants will be constructed and tested:

- A tri-generation plant that will be installed in Torino (Italy) in a series lecture halls building identified as “ICE-Desiccant” (hereinafter ICED) that combines an advanced cogeneration system with a liquid desiccant. The plant capacity will be 120 electrical, 200 kW heating, 212 kW of cooling (external air @ 28.8°C 68% R.H)
- A small size combined cycle cogeneration plant. The Combi System (hereinafter CS) is constituted by two integrated cogenerators powered by different prime movers: an innovative reciprocating engine cogenerator (the same of ICED) and a Rankine engine system (bottoming cycle) operated on the exhaust gases of the reciprocating engine. Such plant will be installed and test in Turkey at Middle Technical University. The plant capacity will be 145 electrical and 166 kW heating
- A trigeneration plant that will be installed in Spain to perform the energy service to an office building This application foresees the

integration of a microturbine cogenerator with an ammonia-water absorption cycle.

The three demonstrators are diversified in technologies (e.g. prime mover and cooling system), in capacity and in functions aiming at achieving general results and at addressing a wide spectrum of potential end use applications of the residential, tertiary and industrial sectors.

2. FIAT RESEARCH CENTER CONTINUOUS COGENERATOR: ICED AND CS PRIME MOVER

Both ICED and CS applications are built on an innovative cogeneration system developed by FIAT Research Center (Patented technology) called Continuous Co generator based on an Automotive Internal Combustion engine.

The main innovations are:

- Power regulation at variable speed
- Full automation and telematic management.
- Ultra Low emission
- Embedded UPS
- Embedded load power factor control
- Active filtering
- Capability to deliver reactive power^{vi} for Voltage control.

Due to the application of an advanced high efficiency engine, the CRF system shows higher efficiency at rated power than concurrent systems (32,5% vs 28% of microturbines). At partial loads the efficiency, thanks to the variable RPM power control, remain almost constant (30% @ 30% of rated power).

The nearly constant efficiency at partial loads provides the CRF system with a unique capability of following variable demand load profiles in a profitable way (see figure 1).

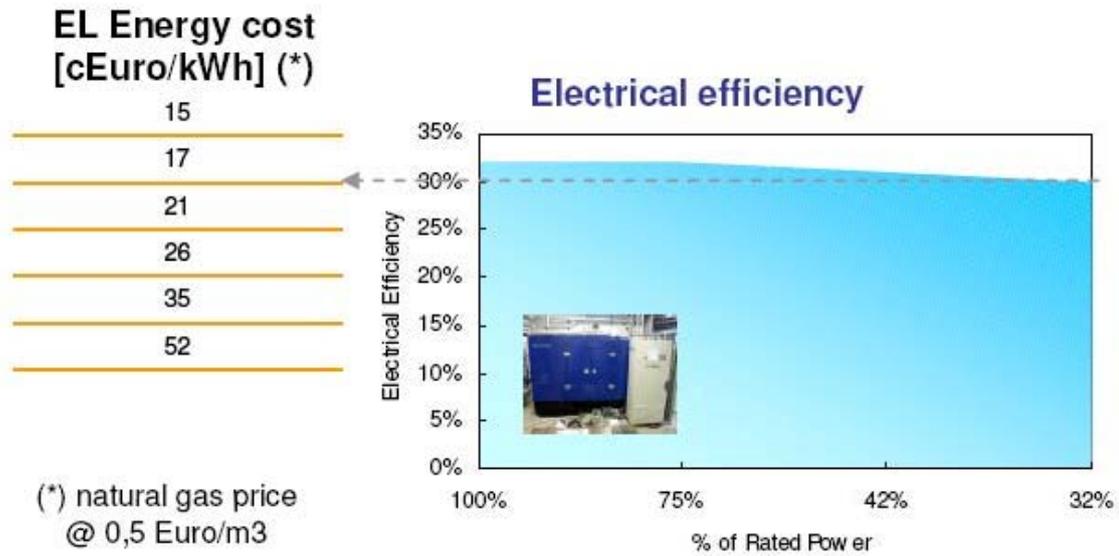


Figure 1- Electricity cost at different level of efficiency for CRF system

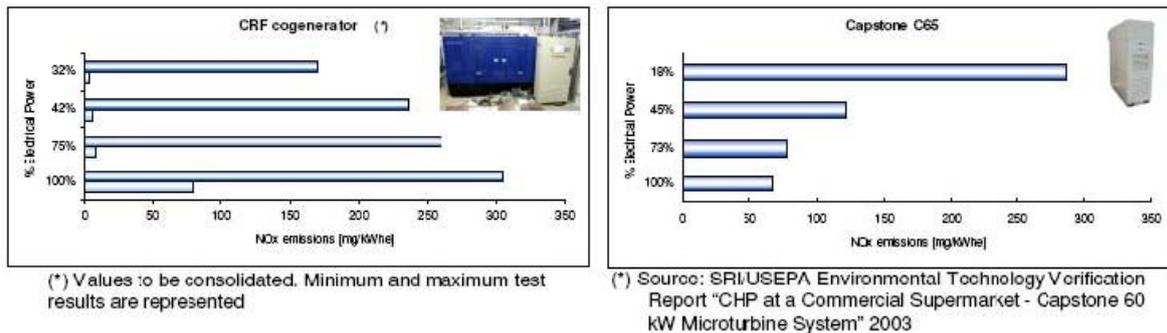


Figure 2- Emission comparison with Microturbines.

Another advantage that arise from the application of ecological new generation engines is that the emissions are comparable with microturbines at rated power (80÷305 vs 68 mg/kWhe) emissions are lower at partial loads see figure 2.

The systems locally emit less pollutants than a high quality natural gas boiler to produce the same amount of heat so the electrical power could be considered "emission neutral". Table 1 Comparison with power generation technologies emissions

Table 1 Comparison with power generation technologies emissions

Emissions of different natural gas systems	NOx (*) [mg/m ³]	NOx [mg/kWhe]	NOx [mg/kWh _t]
CRF system	< 50	< 190	< 120
Best technology power generation (CCGT)	130	300	-
Best technology boiler	90	-	120

The main data of the system are:

Nominal electrical power 120 kW
 Nominal thermal power 190 kW
 Dimensions 3,6 m x 1,2m x 1,9m
 Engine type FPT Tector
 Displacement 5883
 Cylinders arrangement 6L
 Fuel Natural Gas
 Compression ratio 11:1



Figure 3 Continuous co-generator main Characteristic

3. ICED

The ICED (Internal Combustion Engine and Desiccant) application will be a system providing trigeneration by the integration of a gas fuelled cogenerator based on an internal combustion engine and a thermally activated desiccant system.

Heat and cooling distribution are assumed to be based on an all-air system, with one or more Air Handling Units (AHU).

3.1 Liquid Desiccant

The liquid desiccant technologies could be classified among the Thermally Activated air Conditioning technologies (TAC). In the desiccant system supply air passes through an honey comb matrix containing the absorbing substance that is exposed to the supply air stream. In this process the air is dried. The system is similar to conventional solid desiccant except that the absorbing substance exposed to the supply air stream is liquid.

One advantage of liquid desiccant is that the absorbing substance can be previously cooled, thus providing both sensible and latent cooling when put into contact in the process air.

The other advantage is the possibility of storing concentrated liquid desiccant solutions (obtained when regeneration heat is available), thus creating a buffer of

cooling potential, stored as chemical energy, available when dehumidification is needed. The most common liquid desiccants adopted are solution of LiCl or CaCl₂^{vii}. The solution is regenerated using cogenerator as energy source.

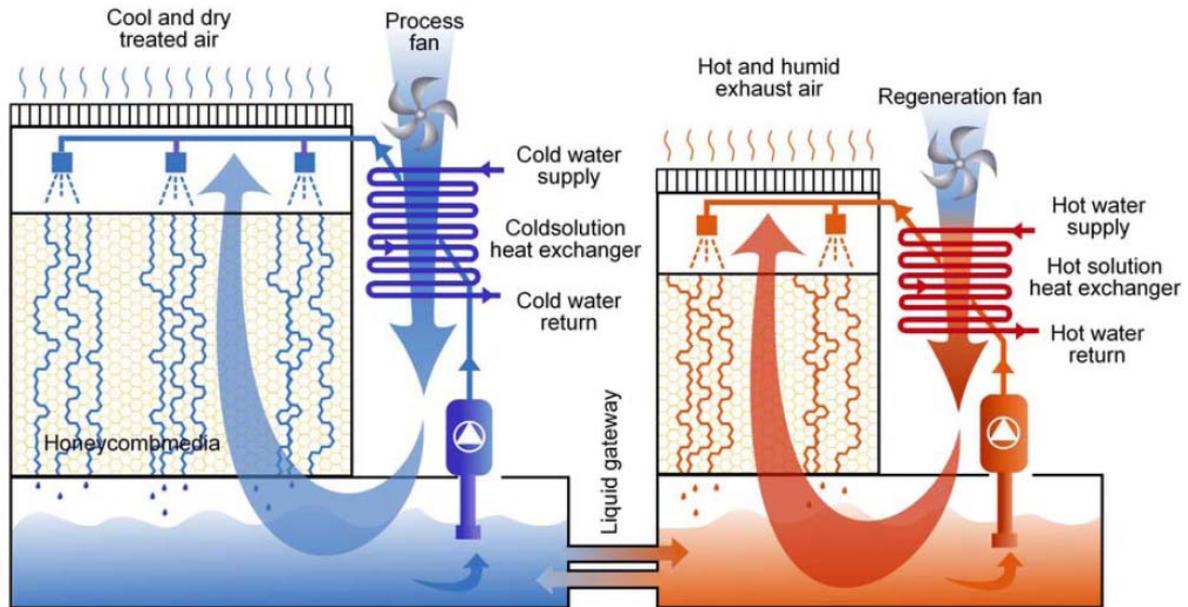


Figure 4 Liquid desiccant scheme

The TAC desiccant cooling system (Thermally Activated air Conditioner) is expected to have:

- High efficiency: overall expected cop exceeding 1.
- Humidity control: built in the desiccant control.
- High air quality: obtained trough humidity control and trough efficiency in latent loads handling.
- High flexibility of heat input: operation will be possible at lower inlet temperatures (with respect to present technology) and even with fluctuating temperatures.

3.2 The working principle of the plant

In desiccant cooling the path followed on the psychrometric chart to reach the desired treated air conditions (1), starting from external or mixed air, is completely different than conventional one. The that will be adopted can be described in the

following scheme:

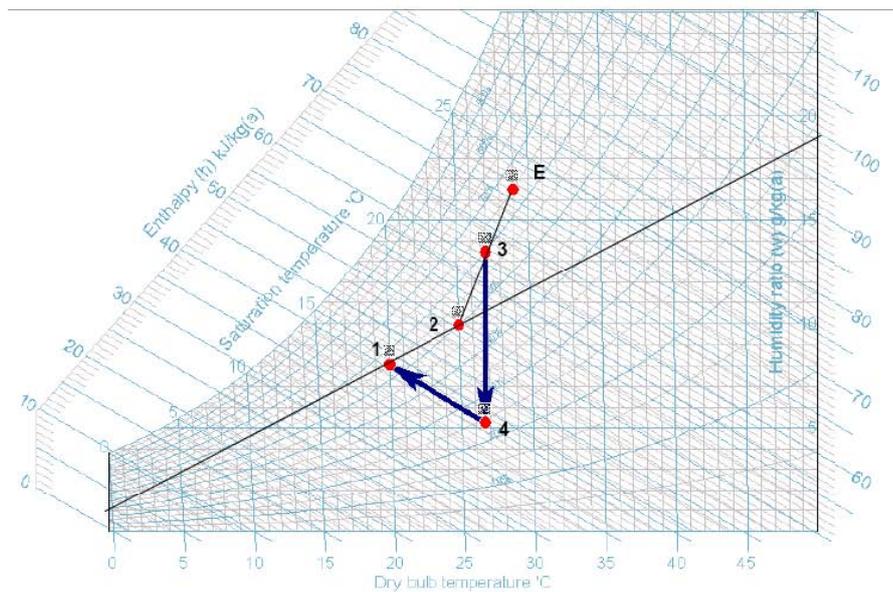
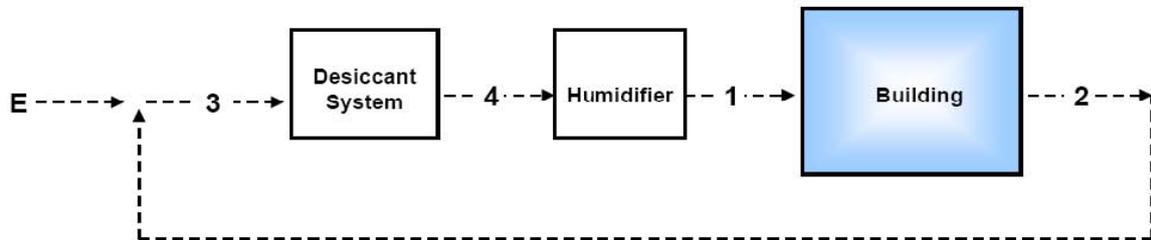


Figure 5 Isothermal dehumidification followed by adiabatic saturation

The external air condition is labelled as E and mixed with recirculated air in condition 2, the result of mixing is indicated in point 3. Supply air must be provided at condition 1. The first step is to go from mixed air to supply air is obtained through

dehumidification of air in 3 without modification of dry-bulb temperature (vertical arrow). This is an ideal situation in which there is no sensible heating/cooling.

Once air is dehumidified down to point 4, evaporative cooling adds moisture to reach point 1. This process is ideally considered adiabatic: there's no enthalpy gain, the arrow between 4 and 1 is parallel to the constant enthalpy lines. This is

obtained by spraying water into the supply air stream. Note that the length of the “dehumidification” arrow (from 3 to 4) related to latent cooling depends on the intersection between the constant enthalpy line passing through point 1 and the vertical line passing through point 3. The advantage in this process is that moisture removal (vertical arrow) can be obtained through desiccant systems, that is to say using waste heat as energy source. During desiccant cooling process treated air temperature increases because of:

thermal exchanges with the warm desiccant coming from the regenerator (where desiccant is dried by using heat)

heat of condensation of absorbed water vapour If heat is not removed in the desiccant cooling conditioner, treated air will be provided at lower humidity ratio but higher temperatures (this is common in solid desiccant systems like rotating wheels). One source of sensible cooling is needed to maintain the line from 3 to 4 vertical or, better yet, to provide sensible cooling by lowering the treated dry-bulb temperature. The advantage of liquid desiccant systems is that the water-desiccant solution can be directly cooled to remove heat and provide additional sensible cooling. Cool water coming from an evaporative tower will be the cooling source for the desiccant solution.

3.3 The plant

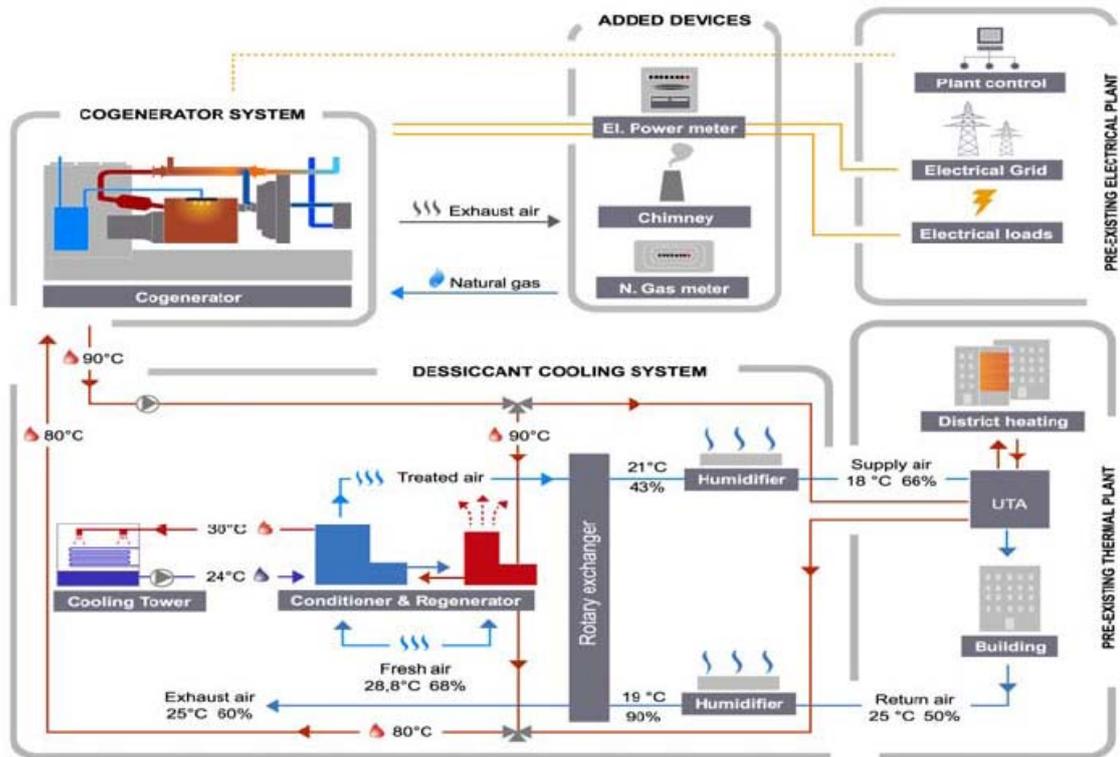
The following are the estimated values plants performances:

Table 2 winter behaviour

	Full load (100% nominal)	Part load (49% nominal)
Primary fuel	355	177
El. Power (to the grid)	118	59
Th. Power	186	93.9
Global efficiency	85 %	86 %
Electrical efficiency	33 %	33 %
Thermal efficiency	52 %	53 %

Table 3 winter behaviour Figure 6 Plant Concept Scheme.

	Full load (100% nominal)
External air	28.8°C 68% R.H.
Supply air	18°C 66% R.H.
Primary fuel	355
El. Power (to the grid)	118 (1.6+1.6+1.6)x4)ausiliari = 92.8
Th. power	186
Cooling power delivered	44rot-exch+ (42 x4)DessUnits = 212
External air	28.8°C 68% R.H.
Supply air	18°C 66% R.H.



4. COMBI SYSTEM

The architecture of the system is a combination of two cogenerators based on different prime movers: a reciprocating engine cogenerator as topping cycle 'COG1', and a Rankine cycle operating on the exhaust gases of the reciprocating engine as

bottoming cycle 'COG2'. One of the main developments is to achieve very high electrical efficiency (target 40%+):

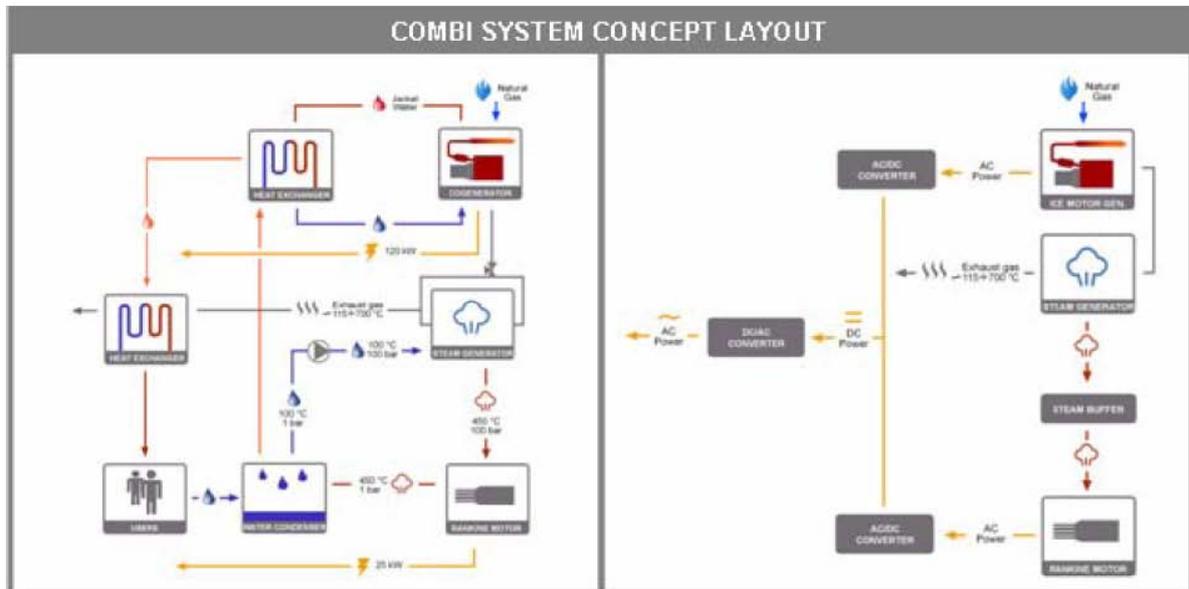


Figure 7 Combi System Concept

Reciprocating engine cogenerator – COG1 It's an internal combustion engine (ICE) and its distinctive feature is the capability of regulating power at constant electrical efficiency. Rankine cycle cogenerator – COG2 It's a separate module based on a Rankine cycle. The prime mover is a steam engine. It will be coupled with COG1 in order to exploit the residual energy in CHP exhaust gases.

4.1 Performance

Electrical efficiency, emissions (per kWh) and power quality are expected to be very high not only at full load, but also at part load (30%-). Overall efficiency is expected to be comparable with state of art cogeneration systems.

The project guidelines are maximizing electrical and thermal efficiency; minimizing pollution in economic sustainable perspective. Hereinafter a table is presented with the expected balance of plant.

Table 4 Balance of plant

	42%Nominal	75%Nominal	Nominal
Power to the grid [kW]	67.1	103.8	142.3
Power COG 1[kW]	58.8	88.2	117.6
Power COG 2 [kW]	8.3	15.6	24.7
Heat to user [kW]	82.9	120.2	166.7
Heat COG 1 [kW]	61.6	80.4	103.0
Heat COG 2 [kW]	21.3	39.7	63.8
Fuel input [kW]	176.9	259.7	355.2
Fuel consumption [Nm ³ /h]	19.4	28.4	38.9
Electric efficiency	38%	40%	40%
Thermal efficiency	47%	46%	47%
Total efficiency (electric-thermal)	85%	86%	87%

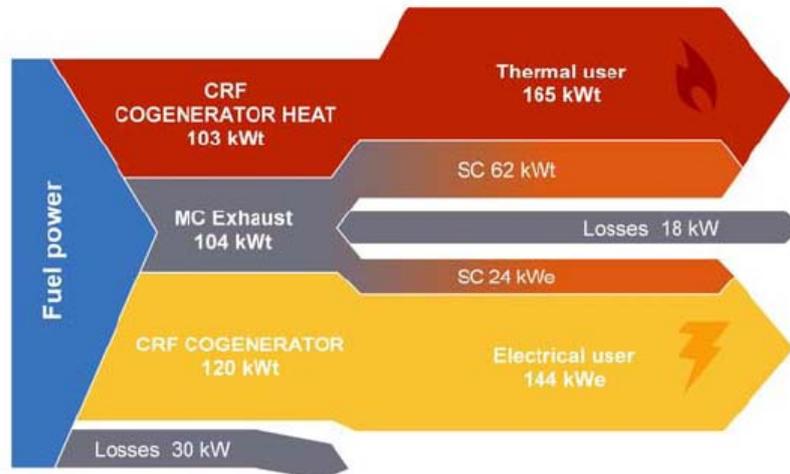


Figure 8-Sankey Diagram

5. MTA

The main objective of the Micro Turbine-Absorption (MTA) project is to develop and demonstrate the high efficiency of a micro-trigeneration system with the

integration of a Microturbine with absorption chillers. Therefore to obtain a compact, cost effective and high flexibility solution.

The trigeneration system is constituted by two integrated subsystems:

- A natural gas microturbine cogenerator
- An absorption chiller (transform waste heat into cooling)

In these systems the Micro Gas Turbine exhaust gas is the heating medium to drive the chiller. Also post-combustion natural gas is used to increase the cooling capacity of the system. The main advantages of the new technology over the conventional system are that the COP of the chillers is higher because they are driven by higher temperatures, the production of electricity and chilled water is decoupled and there is a wider range of chilled production capacity.

The optimal chiller would be without cooling tower, directly by exhaust gas fired, with a high COP and with an important chiller capacity.

The final MTA configuration will be the integration of two hot oil driven Robur absorption chillers of 17 kW each to the microturbine Capstone C65. In this selected configuration the heat rejected from the absorption chillers is removed using ambient air so it is not necessary to use a cooling tower with all the corresponding advantages.

5.1 The building

The selected building has been chosen between different alternatives due to the fact that electrical load is almost constant throughout the year. In this way the MTA can be run as base load during a long period per year.

The building has a total surface of 9.559,29 m², around the 50% of the surface is housing, around 30% are Offices and the rest are Commercial Centres. The heating demand of the multifunctional building is 1.174.043 kWh a year and the cooling demand 350.468 kWh per year.

The MTA equipment should supply a cooling capacity around 21.600 kWh out of the 350.468 kWh that the building needs.

Building facilities:

- Commercial centres.
- Offices.
- State subsidized housing and rented flats for young people
- • Parking. In the beginning the Market and the Supermarket were a part of the project but in the end they are not included in the centralised energy supply system of the building complex.

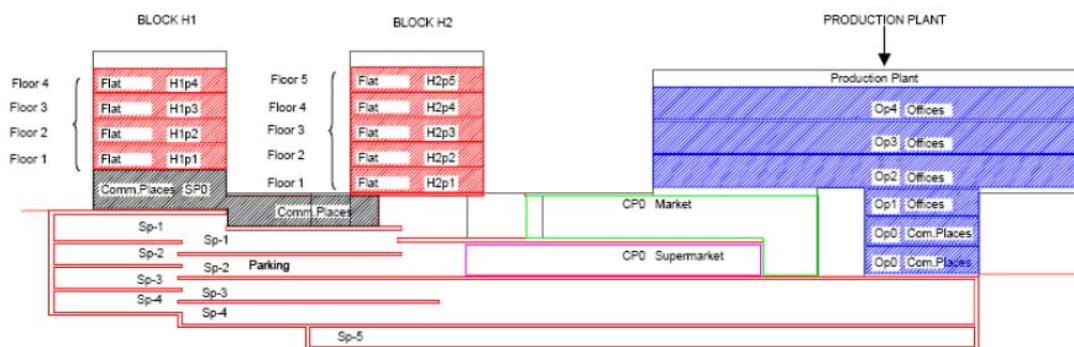


Figure 9 Vertical distribution of the grid

6. BIBLIOGRAPHY

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- [2] ENERGY FUTURES The role of research and technological development- 2006 Directorate-General for Research Sustainable Energy Systems
- [3] 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

- i Co financed by European Commission under priority 6.1 of 6th Framework programme
- ii www.hegelproject.eu
- iii Hereinafter “trigeneration” means combined production of power, heating and cooling, “micro” means a system with capacity lower than 1 MWe (according to EU Directive).
- iv Energy Efficiency Action Plan (COM (2006) 545 final)
- v ENERGY FUTURES The role of research and technological development 2006 Directorate-General for Research Sustainable Energy Systems
- vi The system is conceived to deliver also ancillary services to the electrical grid if requested by utility
- vii Lithium Chloride or Calcium Chloride.