DOMESTIC POLYGENERATION PRACTICES FOR ENERGY SAVING IN BUILDING

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Summary

During last years, in Mediterranean and Central Europe area, during warm season, has growth the demand of cooling energy in domestic sector generally satisfied by electrically-driven units; this trend has involved an increase of power generation capacity of electric utilities and a summer peak load of electric energy consumption with the related problem of some electric black-out. This problem has been the driving force to an increasing interest to small scale polygeneration systems fuelled by natural gas.

At the Built Environment Control Laboratory of Seconda Università di Napoli, is running a system based on gas fuelled internal combustion engine coupled with an Air Cooled Water Chiller, ACWC, and a Thermochemical absorption system; the assembly supplies thermal (heating and hot water, 12 kW), electrical (6 kW) and cooling energy (7.5 kW) to a part of a building with offices and laboratories under actual operating conditions; of course the proposed system will satisfy all year around an electric load, while for conditioning purpose it satisfies during cold season the user thermal requirements (heating and hot water) by means an appropriate thermal storage of 1000 lt, and during summer season the cooling and hot water requests. This test facility is equipped with measurement systems based on sensors linked to a data acquisition systems, designed and built to evaluate energetic and environmental performances in actual operating condition

The paper deals with the applications of this Micro Combined Cooling, Heating and Power systems, or so-called MicroPolygeneration, under real operating condition for mild climate with the aim of evaluating their potential employment in building conditioning systems. So the experimental set-up are described with the first results of systems performances in terms of energetic analysis.

Keywords: Polygeneration, Gas fuelled, ThermoChemical Absorption, CHP.

1 Introduction

The terms polygeneration (or trigeneration) is usually referred to an energy conversion process with Combined Cooling, Heating and Power generation, CCHP, starting from a primary fuel; the processes and available technologies are nowadays well established, and lead to a consistent primary energy saving with respect to the energy separate production.

The system consists basically of a CHP (Combined Heat & Power) module generating electricity and heat that, depending on the demand, can be simply used for heating and hot water purposes; this basic assembly has an application area that ranges from large commercial buildings (office, hotels, schools, sports, entertainment centers, hospitals, airports, etc.), to industry facilities [1,2].

Considering the residential buildings application, the cogeneration deployment is economically, energetically and environmentally affected by the opportunity to recover the waste heat energy during summer season; the abovementioned basic and well known cogeneration must be developed into polygeneration. In this application the system should produce electricity and use waste heat for user thermal requirements (heating and hot water) during cold season, whilst during summer season the waste heat is used for cooling and hot water requests.

To this aim is noteworthy the availability of small Thermally Driven Cooling (TDC) systems with cooling capacities of 30 kW down to a few kW, that have been developed by a number of European companies and are recently transferred into the market [3]:

- The absorption Lithium-bromide – water systems are a well-established cooling technology since many years. Many manufacturers are active in the market for large capacity systems, both for single-effect and double-effect machines. Recently, small-capacity single-effect systems with cooling powers around 5 to 30 kW have been developed and are now available on the market. Four-five new products have been available in the cooling capacity range < 30 kW (Yazaki WFC-SC5 17.5 kW, Sonnenklima Suninverse 10 kW, EAW 15 kW, Rotartica 4.5 kW, Broad BCT 16 kW, ABAKUS 4.5 kW).
- The absorption water – ammonia technology is well known and developed for large capacities. Direct gas-fired systems are also well established whilst few small capacity hot-water machines are available or close to market (Pink /SolarNext 12kW, Robur 17kW, AoSol 8kW); several groups are working on new developments (Helioplus 5kW, ITW 10 kW, DAKM 3kW).
- The LiCl – water absorption system (Thermo Chemical Accumulator TCA) has been developed by the Swedish company ClimateWell. It uses the crystallization effect in order to increase energy density and through the accumulation of salt crystals it functions as a heat/cold storage. The machine operates intermittently and in order to allow a continuous operation a two-barrel system has been developed. The cooling power is variable in the 2-12 kW range.
- Adsorption technology is less developed than absorption, and two adsorption pairs have been used for adsorption chillers up to now: Silica gel – water and zeolite – water. The system is characterized by no moving part, reasonable COP of about 0.5-0.6 and no crystallization risk. In the last few years, new small-capacity machines (7 to 15 kW) have been developed and are available as small series products (SorTech 8&15kW kW, Invensor 7&10kW, SJTU 10kW, ECN 2.5kW).

The major advantage of polygeneration is the efficient fuel usage, that, in comparison with conventional power generation systems can raise up to 60%; this leads to a lot of benefits:

- primary energy saving,
- more efficient fuel usage with saving fuels and money (economical benefits),
- less greenhouse gases produced (climate change mitigation),
- energy security of the country/region,
- positive impact on economy,

Over the benefits abovementioned, it's necessary to underline that, in the last years in many European country, during warm season, there has been an increasing demand of cooling energy generally satisfied by electrically-driven units; this trend has involved an increase of power generation capacity of electric utilities and a summer peak load of electric energy consumption with the related problem of electric black-out. This problem has been the driving force to an increasing interest to micropolygeneration systems fuelled by natural gas, especially in the South of Europe.

Referring to the residential sector, polygeneration potential in buildings in European countries is hard to estimate [4]. This task will be thoroughly studied within the framework of the PolySMART project. Some results has been related to country specific situation: for example CHP (and hence CCHP) potential in UK is estimated to be around 17% of total projected electricity production in 2010. Around 15% of this potential exists in individual buildings. Some 40 million homes in old European Union countries are said to be suitable for micro-CHP (and hence micro-CCHP) systems. Sigma Elektroteknisk of Norway estimates a yearly market potential for Micro-CHP of some 800,000 units per annum only in Europe. Taking under consideration that the cooling market in Europe is far from saturation (with only 2 ÷ 5% air-conditioning units per household) and growing very fast, it can be concluded that strong potential for combined heat cold and power also in buildings exists.

2 Micropolygeneration applications

In Europe a interesting and intensive research activity is in progress on micropolygeneration systems and here are reported some significative experiences based on a common "heart" of the system constituted by an internal combustion engine coupled with a thermally driven cooling units and distribution system usually based on a water hydronic circuit. Following are briefly described the systems assembly:

- Spain, Madrid [5]

The building considered for the project has a trigeneration installation that provide heating and cooling for the main entrance hall that is around 70 m2 area. The micro-cogeneration module is based on a SENERTEC DACHS internal combustion gas fuelled engine, with an electrical production of 5.5 kW and a thermal generation of 12.5 kW. The entrance hall is cooled/heated by two installed fan coils with 10 kW cooling capacity each. The plant includes a ClimateWell's chemical heat pump, model CW10, capable of storing energy and to deliver cooling and heating, up to 20 kW power. The heat rejection is performed by means of a small open cooling tower installed over the building roof. Finally the systems has been equipped with a 750 litres buffer tank that has been installed for heating storage purposes.

- Spain, Vitoria-Gasteiz [6]

The installation is used for indoor conditioning of a corridor (60 m2) and a laboratory (120m2). The heat and cold distribution system are based on fan coils used for corridor and radiant panels on the ceiling for the laboratory. The micropolygeneration is composed by a SENERTEC cogeneration unit and a ROTARTICA rotary absorption machine as TDC. The micro-CHP is gas fuelled and produces 5,5 kW electricity and 12,5 kW heat that is used to provide heating in winter, DHW all around the year, and to drive the TDC to produce cooling for summer. The CHP oulet is directly connected to the TDC in order to reach the maximum tenperature at TDC inlet driving circuit; the thermally driven system used is a Rotartica 045, with a cooling capacity of 4.5 equipped with a dry air cooling tower used for heat rejection. The plant layout has been then implemented with 370 liters for hot storage and 1000 liters for cold storage.

- Germany, Freiburg [7]

The case study concerns installation of a micro-scale trigeneration system in an office building at Fraunhofer ISE in Freiburg where the system delivers heat and cold; the heat and cold distribution systems is based on fan coils and on PCM chilled ceilings.

A Tedom Mirco S8 natural gas fired internal combustion engine with 8kW electric and 19kW thermal power has been installed, whilst the TDC is based on 2 SorTech silica gel adsorption chillers with 5,5kW cooling power each.

The CHP generates power fed to grid and heat; during the heating season, the heat from CHP is used for space heating of the building with district heating network and oil boiler as back-up. During summer, the heat is used to drive two adsorption chillers.

Three storage tanks are installed; two on the hot side, one on the chilled water side. On the hot side a 1000 liters hot water storage tank is installed in the CHP outlet, a 600 liters mixing storage is installed in the TDC. A 1000 liters chilled water tank is installed in the chilled water circuit in order to provide some chilled water storage and act as a hydraulic switch.

- Northern Ireland, University of Ulster [8]

A household size trigeneration based on a small-scale diesel engine generator set has been realized in laboratory with the aim to perform experimental tests to evaluate the performance and emissions of the diesel engine generator and of the whole trigeneration. The prime mover used is a Lister–Petter T series engine, with a 9.5 kW capacity; it is an air-cooled, direct injection diesel engine. As ccoling component is used an Electrolux absorption refrigerator which utilizes the exhaust heat from the engine to generate refrigeration effect. It can be powered by electricity or liquefied petroleum gas.

- Portugal, Porto Alto [9]

This demonstration project is designed to acclimatize a showroom and office rooms at AoSol office building. The prime mover considered is a Senertech 5,5 kW unit that feed a 1000 liters hot water storage and warm up a DHW tank (0,4 m3). The storage tank is used as a buffer between the CHP and the TDC / heat sink. The office cooling is performed by an absirption chille (8 kW cooling capacity)

- Portugal, Lisboa [10]

This project is intended for the climatization of a total floor area of 175 m2 at INETI building; the two rooms are respectively a lecture room and an office room.

The CHP is biodiesel fuelled engine that warms up a DHW tank (300 liters); an hot water storage tank (500 liters) is further used as a buffer between the CHP and the TDC / heat sink. A cold water buffer (500 liters) is used between the TDC and the cold sink.

AOSOL–solar collector factory is responsible for the development of the air-cooled ammonia-water absorption chiller used in both Portuguese plants.

- Germany, Diessen [11]

The system application is related to offices and to a showroom and will cover the heating and cooling demand as well as the demand for domestic hot water for the whole building, allowing the CHP to have a sufficient operating time.

The operating power is served by 2 Senertec Dachs Combined-Heat-Power (CHP) machines with a total electric capacity of 11 kW; they are fuelled by liquid gas. The cooling requirements is satisfied by a SK Sonnenklima 10kW absorption chiller. A hot water buffer storage 550 liters is warmt up by the CHP.

3 Micropolygeneration applications

A promising application of polygeneration is in this paper referred to a mild climatic condition such those existing in South Italy, where the authors are investigating the on-site performances of micropolygeneration under real operating condition [12]. As previously referred, during warm season, there has been an increasing demand of cooling energy generally satisfied by electrically-driven units with an increase of power generation capacity of electric utilities and a summer peak load of electric energy consumption; a solution to mitigate the problem consists in cooling systems fuelled by natural gas.

At the Built Environment Control Laboratory of Seconda Università di Napoli, a micropolygeneration system based on gas fuelled internal combustion engine has been coupled with an Air Cooled Water Chiller, ACWC and a Thermal-Chemical Accumulator, TCA; the last is a thermally driven cooling technology appeared recently on the market; it was set up in Frignano (Lat. 40°59'56"76 N; Long. 14°10'48"00 E), it is a municipality in the Province of Caserta in the Italian region Campania, located about 20 km northwest of Naples. The system is able to supply thermal (heating and hot water, 11 kW), electrical (6 kW) and cooling energy (17.5 kW considering nominal values for TCA and ACWC) to a part of a building with offices and laboratories under actual operating conditions.

During the cold season the system supplies electricity for lighting, PC's and other electric equipments located in two offices, while remaining thermal energy is stored in a 1000 liters tank for offices heating and hot water requirements for all the occupants of the building as reported in figure 1. The storage tank is furthermore equipped with an auxiliary electric resistance of 4 kW that is fed by the microcogenerator (micro-CHP).

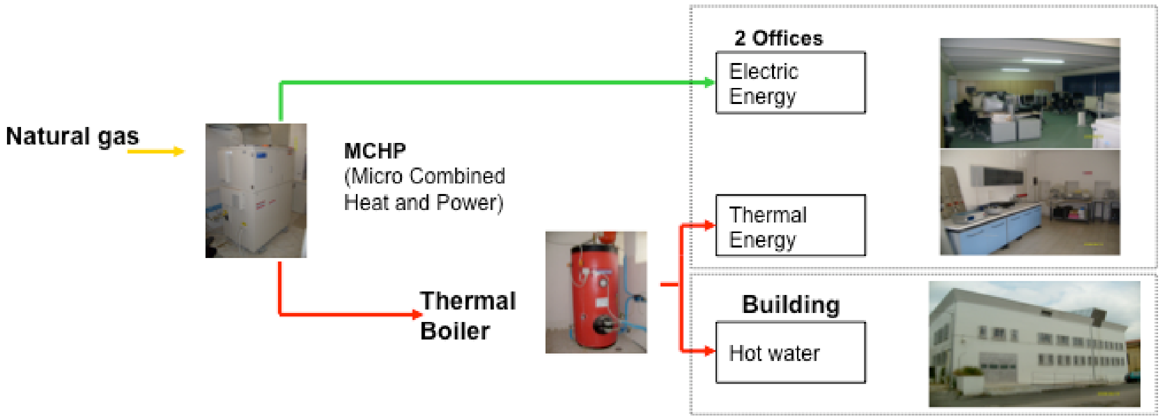

Fig. 1 Micropolygeneration in winter mode

During the warm season the experimental plant has the opportunity to operate with two different micro-polygeneration modes: a micro-CHP/ACWC system and a micro-CHP/TCA system, that are also able to function simultaneously as reported in figure 2. In this operating mode the ACWC is supplied by the electrical output of the micro-CHP (2.5 kW), while the remaining part is supplied for the laboratory uses (up to 3.5 kW)

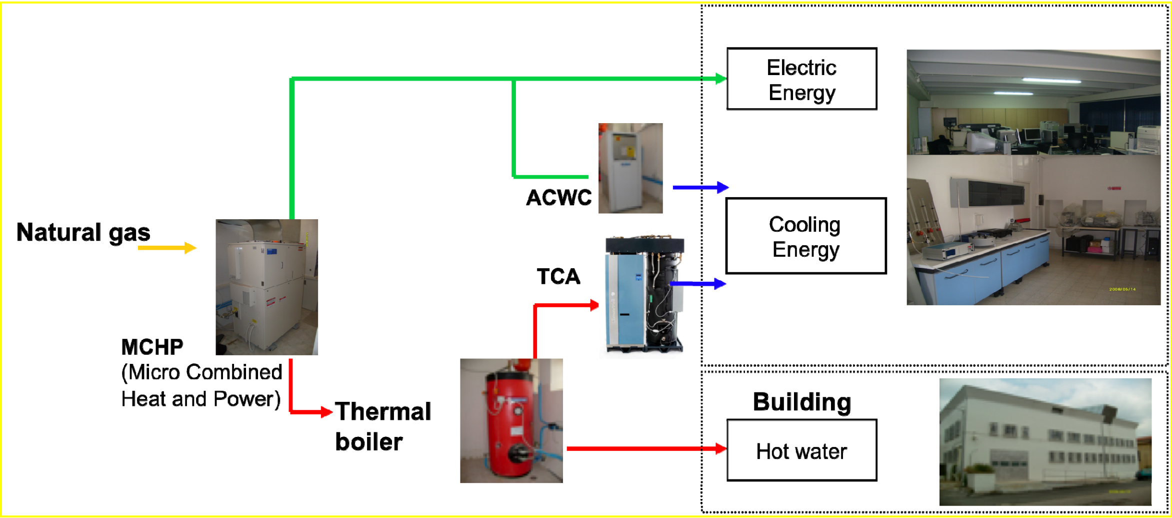

Fig. 2 Micropolygeneration in summer mode

The main reasons that lead to the use of double cooling system are based on:

- the possibility of driving ACWC by electric grid whereas a engine failure occurs or a more convenient energy cost is achievable,
- the availability of a system with an high flexibility levels of operating modes allows to find the optimum match between the equipment and the end-user load profile ie. to follow the energetic and economic advantages,
- a mass production ACWC units utilization to reduce the plant first-cost.

Nevertheless a great quantity of thermal energy produced by micro-CHP is not used in hot season and in this period the energetic performance of the system is unsatisfactory: for this reason it was taken into account an adsorption chiller with Thermal-chemical Accumulator (TCA) able to use thermal energy stored in hot season. In order to supply water at the requested temperature for the TCA operations, a gas fired boiler (efficiency 90%) has been placed in series with the hot storage tank. Because the TCA requests a charging temperature not less than 50 °C respect to the external air temperature, the MCHP system has the function to keep a medium water temperature in the heat storage whereas the gas fired boiler ensures the high temperature inlet to charge the TCA.

As reported figure 3, the plant is composed of different hydronic closed circuits to consider the summer and winter operation with the heat and cold distribution systems based on fan coils.

The system is investigated by the Energetic, Economic and Environmental approach (3-E analysis), by which the performances of system proposed (ie. the Alternative System), are compared to that ones of Conventional energy System, CS, based on separate “production”. In order to perform the abovementioned comparison in terms of energetic balances, the whole system (MCHP/ACWC/TCA) considered, has been equipped with a data measurement and acquisition system as follows:

- Mass flow sensor for methane,
- Ultrasonic mass flow sensor for water,
- Temperature sensors, model TT-227/Pt100,
- Watt-meters with measuring range 0-6 kW,
- Watt-meters with measuring range 0-10 kW,
- Exhaust gas analyzer.

The data acquisition systems has been set up with field point I/O system with FP-AI-100 modules to acquire signals by analogical output 4÷20 mA and RTD-124 modules to acquire signals by PT100; the data management has been finally performed by the LabView software.

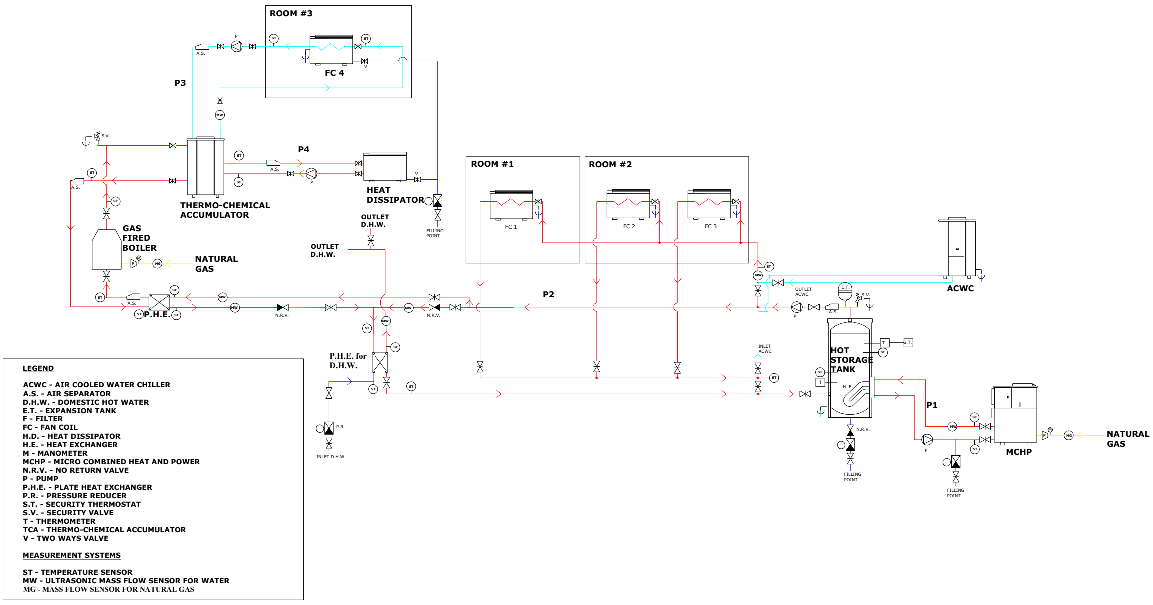

Fig. 3 Micropolygeneration plant layout

4 First experimental results

The system considered is in a start-up phase with some data gathered randomly during summer 2009 and the results are referred to a short acquisition period (2 - 3 days), with the system running in micro-CHP/ACWC mode only.

Figure 4 reports the temperatures gathered during the trial in some key-points of the plant: micro-CHP outlet, hot storage and external. The micro-CHP outlet temperature has an overall increase of 30 °C (from 40 °C up to 70 °C) during six hours of functioning; this amount has been achieved in three different steps of ΔT= 10 °C each; from 40 °C to 50 °C in the starting minutes, from 50 °C to 60 °C in about 1 hour and finally the remaining 10 °C during the afternoon. At the same time the storage temperature shows a slightly sloping up to its maximum temperature of about 68 °C, with different ranges of temperature increasing rate durng the acquisition; this is a very challenging topic about the polygeneration system under study and its application for "summer" air conditioning with thermally driven cooling ssytem. To this aim the system should go as soon as possible to its maximum temperature to supply hot water to the TCA cooling system and to get the highest efficiency; so a domestic boiler it has been necessary to improve TCA inlet temperature. An obviuos future development of the plant would consist in using a suitable solar collector to push the water temperature up to 90 - 95 °C. Considering the cooling circuit it can be noted that the system is characterized by frequent on-off operation with a subsequent temperatures fluctuation at the inlet (and outlet) of the fan-coils hydronic circuit.

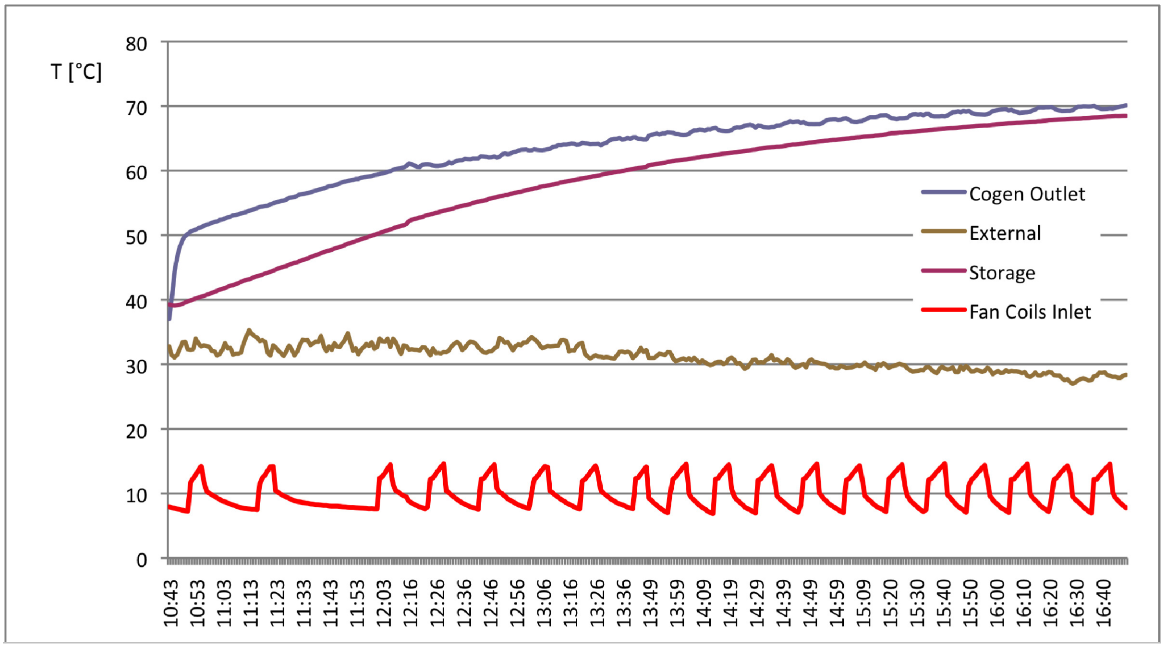

Fig. 4 Temperature increase

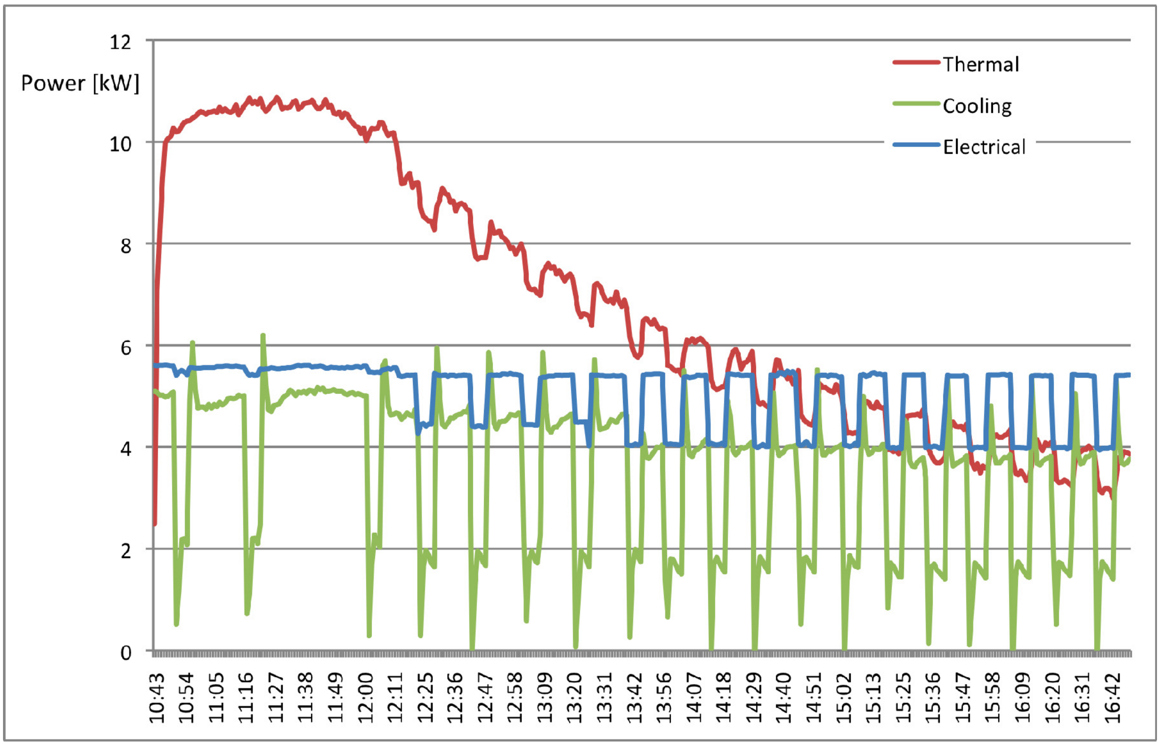

Fig. 5 Power delivered

Figure 5 reports the thermal, electrical and cooling power delivered by micro-CHP/ACWC polygeneration system in a single day acquisition. From the lines trend it can be possible to observe that the thermal power delivered by micro-CHP raises quickly up to 10 kW few minutes after it was switched on and successively it raise up to the highest value of 11 kW after 1/2 hour of functioning; this value is held fairly constant till midday; after this period the delivered thermal power decreases with a sequence of downgrading steps corresponding to the on (lower) and off (upper) operation of the ACWC system. As before stated the ACWC power line with values referred to the cooling capacity shows a frequent on-off operation; from this trend it can be inferred that the large commercially available cooling unit considered has a very poor performances in term of COP and a more efficient unit, equipped with the most advanced technology like multi sensors electronic inverter, is therefore required for a better performance. Furthermore, it clearly appears that a suitable water storage system is necessary for the cooling circuit, to set a nearly constant temperature for the inlet and outlet of fan-coils circuit. The frequent on-off operation have also influence on thermal and electrical power delivered by micro-CHP .

5 Conclusions

In this paper a framework about the current status on micropolygeneration applications has been reported considering several projects developed and supported for utilization in the building sector. A case study of micropolygeneration applications is reported with the description of the plant functioning in a offices and laboratory building in South Italy.

The application of this technology in small building sector, appears very promising considering that, at the moment, it is in progress a transition from conventional centralized energy systems, based on separate "production", to the incoming decentralized ones, thanks to the market availability of a wide variety of small scale power and heat pump systems (electrically and thermally driven), allowing to satisfy different energy requirements (electricity, cooling and heating) with a great potential of primary energy saving and greenhouse gas emission reduction.

First trials have been performed on micropolygeneration system in the set-up phase, and this revealed some intrinsic limits mainly related to waste thermal heat recovered from engine to the storage tank: the maximum water temperature is not enough suitable for an efficient utilization in the thermally drvien cooling system as well as the ACWC used has frequently on-off operations. Practical experience is then necessary for the systems that shows operability but need to be optimised.

In the research follow-on the aim is to start with a field test on medium and log term periods to find the best operating conditions not only with regards the optimization of energetic performance of the polygeneration system, but also on the optimization between the system and the user load profile to define several operating strategy and their impact on system optimum performance.

Acknowledgments

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