POLYCITY - CERDANYOLA / SPAIN: INTEGRATION OF RENEWABLES INTO THE DHC NETWORK - OPTIMISATION AND ENERGY ASSESSMENT

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ABSTRACT

Distributed polygeneration systems including renewable energy sources connected to District Heating and Cooling networks for thermal energy distribution and exporting electricity to the grid will play an increasing role in the coming years. The objective of this paper is to describe the present situation in the development of the polygeneration plant providing electricity, heating and cooling to a DHC network in Cerdanyola del Vallès and present the strategy developed to optimise the energy supply system. This facility is built in the framework of the Polycity project.

1. INTRODUCTION AND OBJECTIVES

The European Union is leading the way to reduce the CO_2 due to the human activity developing high energy efficiency measures and technologies to reduce the consumption of primary energy. Among these technologies one of the most important is the development of distributed polygeneration systems including renewable energy sources connected to District Heating and Cooling networks for thermal energy distribution and to the electricity grid.

Polygeneration systems produce power, heating and cooling at different conditions and at a higher efficiency than conventional systems, integrating several technologies and including renewable energy sources. The integration of polygeneration system into district heating and cooling networks (DHC) is an alternative to the conventional system where each commercial building or each dwelling purchases the electricity from the grid and covers its own heating and cooling demand locally. Energy integrated polygeneration plants decrease the consumption of primary energy and the global emission of contaminants. Moreover, DHC is important for implementing CHP because it expands the pool of potential users of recovered thermal energy beyond the industrial sector to include commercial, institutional and multi-unit residential buildings.

In spite of the many economic and environmental benefits of district heating and cooling networks based on combined heat and power, their implementation at the present time is not so high as it would be expected. However, today's technological developments such as the introduction of energy meters, automated regulation, variable speed pumps, reliable processes for leak detection and development of new and efficient CHP and cooling systems will help to overcome this situation (Camelia, 2007). Moreover, for many local authorities, district heating and cooling using polygeneration is the best means of employment of local resources (biomass, biogas, integrated energy management policies, waste incineration, etc.), and hence a means to reduce the overall energy bill. On the other hand the integration of renewable energy sources in polygeneration plants connected to District Heating and Cooling networks such as the combustion or gasification of biomass, the use of biogas or geothermal energy will play an important role in the near future in these systems.

The objective of this paper is to describe the present situation in the development of the polygeneration plant providing electricity, heating and cooling to a DHC network in Cerdanyola del Vallès. This facility is built in the framework of the Polycity project (Polycity, 2007).

2. DESCRIPTION OF THE ENERGY SUPPLY AND DEMAND SYSTEM

The Polycity project is developed in a new area of 340 hectares in growth located in Cerdanyola del Vallès near Barcelona that at the end will comprise a roof area of 1,890,000 m^2, with a residential area for 15,000 inhabitants and an activity area that will create 40,000 jobs. A high efficiency energy system is to be implemented in the new urban development called Directional Centre, in order to produce electricity, heat and cold. This polygeneration system will comprise natural gas cogeneration plants with an electrical output of about 16 MW_e in a first stage, with thermal cooling facilities (absorption and adsorption chillers) and a district heating and cooling network within the Science and Technology Park, which represents the core of the Directional Centre.

The area will include a Science and Technology Park with the Synchrotron Light Facility (CELLS) as well as residential buildings. The project is focused to the first polygeneration plant (ST4) that will be finished by 2010. ST4 plant will provide electricity, heat and cold energy for the Synchrotron (figure 1) and the technological park buildings through a district heating and cooling network of four tubes. The facility development is managed by the “Consorci del Centre Direccional”, formed by the city council of Cerdanyola del Vallès and the “Institut Català del Sòl”.

Figure 1. Construction progress of the Synchrotron facility as September, 2007.Source: ALBA website (www.cells.es).

The innovative features of the energy supply system include:

1. Storage system for cooling and heating, used to take in the heat and cold variations of demand
2. District heating and cooling network of four tubes for the scientific and technological park
3. Renewable energies integrated in the polygeneration system:

- A biomass gasification plant integrated with cogeneration engines of 1 MWe and fed with wood biomass
- Thermal solar collectors with a total area of up to 2 000m^2 used to produce hot water to drive adsorption chillers.
- At least 1 MW thermal double-effect absorption chiller working in parallel with the single effect absorption chillers and directly driven by the hot exhaust gas from a synthesis gas engine. The system is highly efficient because of the use of a double-effect chiller (COP of up to 1.3) and also because of the direct use

of the waste heat in the chiller generator without any intermediate gas/hot water heat exchanger.

- Up to 1 MW of cooling using an adsorption chiller driven by thermal solar energy at a temperature lower than 90ºC, which will work in parallel with the absorption chillers.

4. High efficiency generation system:

- A natural gas cogeneration plant of 15 MWe based on gas engines. The waste heat given off by the engines is recovered in the form of hot water at a temperature of around 90ºC, used for heating and also to produce chilled water by single-effect water/LiBr absorption chillers of high efficiency.
- Back-up gas boiler system, used for the demand peaks of the thermal energy system or in case of emergency
- Single effect absorption chillers with a total cooling capacity of 9.4 MW driven by using the hot water from the network generated with the engines waste heat and used to supply chilled water to the district cooling network for the air conditioning system
- Compression chillers, used as support of the absorption and adsorption chillers during peak loads

A simplified block diagram for the complete energy supply system of the Cerdanyola site is presented in Figure 2 (Polycity, 2006).

The energy users for the first phase of the Cerdanyola project included in Polycity are the following:

- Synchrotron Light Facility (named ALBA). This is a circular-shaped machine that uses arrays of magnets to generate bright beams of light. It will comprise initially 5 experimental research laboratories called “Beamlines”. This facility will require electricity, building air conditioning, experimental equipment cooling and office heating.

- 534033 m^2 of roof area of buildings hosting the energy supply systems. The required services are the following: electricity, air conditioning and heating.

The configuration of the District heating and cooling network in Cerdanyola will consist of four pipes, with an independent supply and return pipe for heating and cooling delivery. Of course, the investment on this system is most expensive, but as well it is more flexible.

The Consorci del Centre Direccional launched a Call for Tenders to build and operate the polygeneration plant that was awarded on March 1st, 2007 to the joint venture formed by the private companies Tecnocontrol and Lonjas Tecnología.

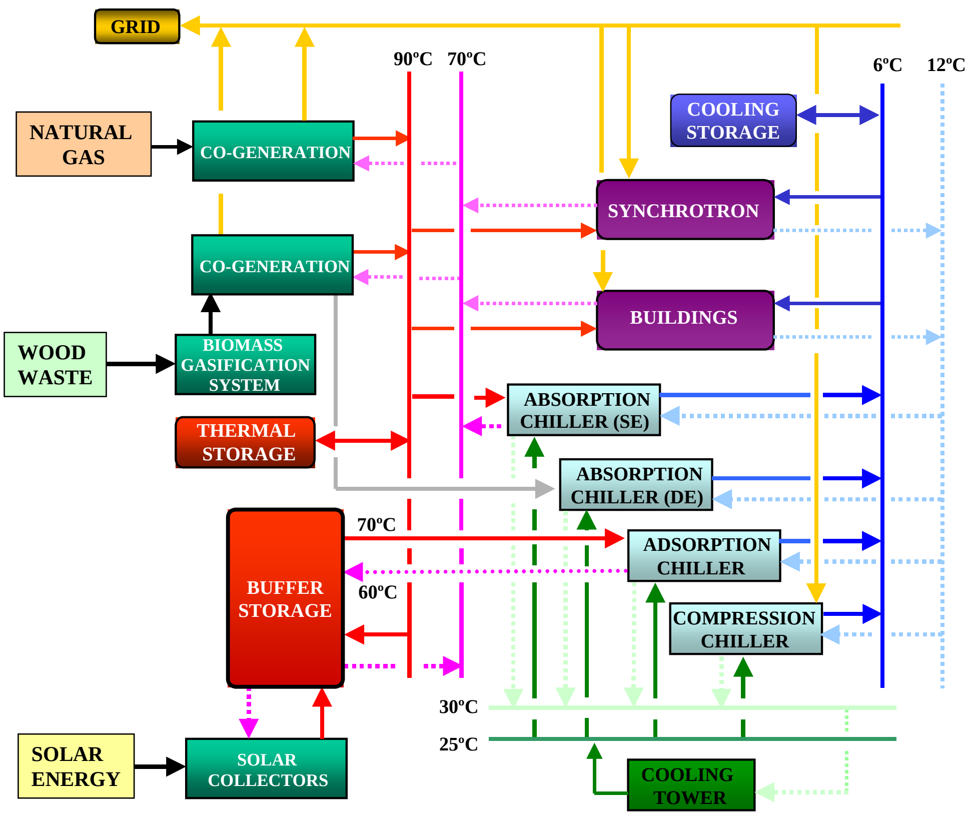

Figure 2. General structure of the energy supply system showing the polygeneration plant and the hot and cold water network

3. EVALUATION OF ALTERNATIVES FOR THE BIOMASS GASIFICATION PLANT

Several commercially available technologies for power generation from biomass such as Organic Rankine Cycles and gasification plants are giving a new impulse to the use of biomass in District Heating and Cooling networks. The Cerdanyola project includes a biomass gasification plant integrated with a cogeneration engine of 1 MWe and fed with wood biomass.

The gasification process is one of the thermochemical conversions that can be used to transform the chemical energy contained in a solid fuel (including biomass) into thermal energy and electricity. The gasification process takes place at around 800-1000°C and needs a moderate supply of oxidant, less than required for a combustion process. The fuel, containing carbon, will react with the oxidant inside the gasification reactor and produce a gas that contains CO, H_2 and other hydrocarbon gases at lower proportions, that is a fuel gas usually called "synthesis gas", and also remainders (ashes) that reach values between 4 % and 12 % according to the used biomass. These remainder by-products are usable for different uses. In any case they can be put in landfills because his character of inert.

The biomass plant will have an estimated consumption of 1.000 kg/h of wood residues. For the use of the synthesis gas in the Cerdanyola cogeneration system two types of alternative configurations have been analysed:

1. Mixing the synthesis gas produced with natural gas and burning the final mixture in all the gas engines. The engines in this case will work at a lower efficiency in comparison with the case in which the engines run only with natural gas.

2. Use a dedicated engine consuming only the synthesis gas. In this case, the efficiency of this engine will be lower.

The second option using dedicated engines was recommended (Polycity, 2006) because in the first case of mixing natural gas and synthesis gas there is an increase in the overall primary energy consumption and CO_2 emissions as all the engines run at a lower efficiency. Figure 3 shows the energy balance for the option using a dedicated engine.

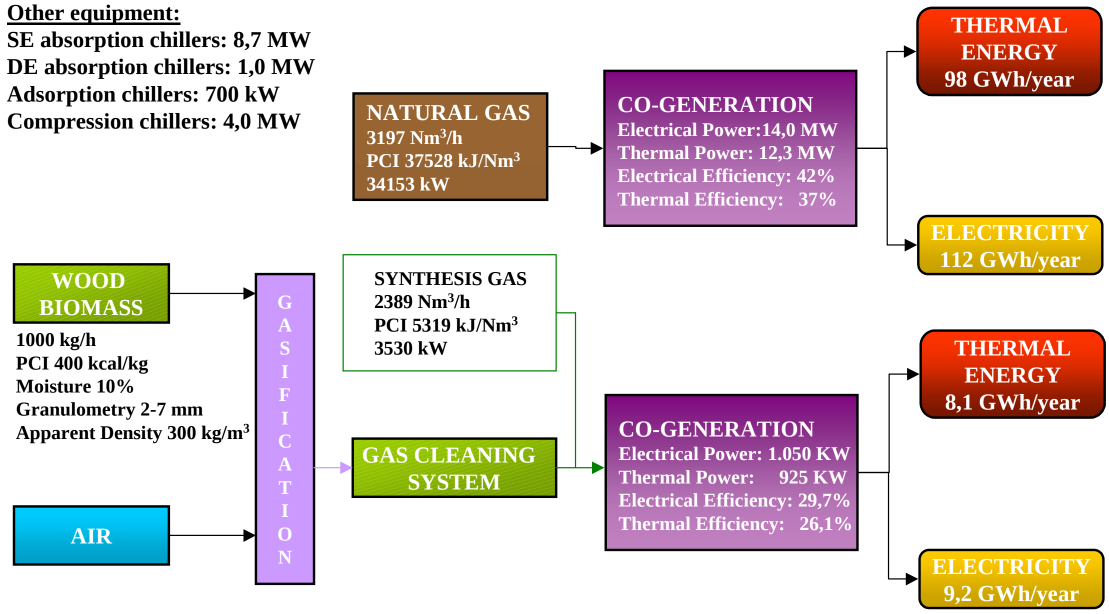

Figure 3. Energy performance of the integrated biomass gasification using separate engines for synthesis and natural gas

4. TECHNO-ECONOMIC EVALUATION OF THE SOLAR COOLING PLANT

Different alternative solar cooling configurations were considered to design the solar cooling plant. The two configurations analysed are: a) the solar plant produces hot water at a relatively high temperature (90ºC) so it can be connected directly to the district heating network and driving an absorption chiller; b) the second one produces hot water at a lower temperature to drive directly an adsorption chiller connected to the district cooling network. In each of these configurations different types of collectors, collector areas and the main operating parameters are be evaluated.

The three solar collector types analysed in this study are: Flat Plate Collector (FPC) (Sonnenkraft SK-500), Evacuated Tube Collector (ETC) (Thermomax Memotron TMO 600) and Compound Parabolic Collector with Evacuated Tube Collector (ETC-CPC) (Sydney SK-6). These collectors are considered facing true South (azimuth = 0º) with a tilt angle of 35º (optimum value to obtain the maximum solar energy yield in a whole year at the latitude of Cerdanyola). With respect to the chillers the models considered are two Mycom ADR-80 and one Thermax LT 21 S for adsorption and absorption, respectively.

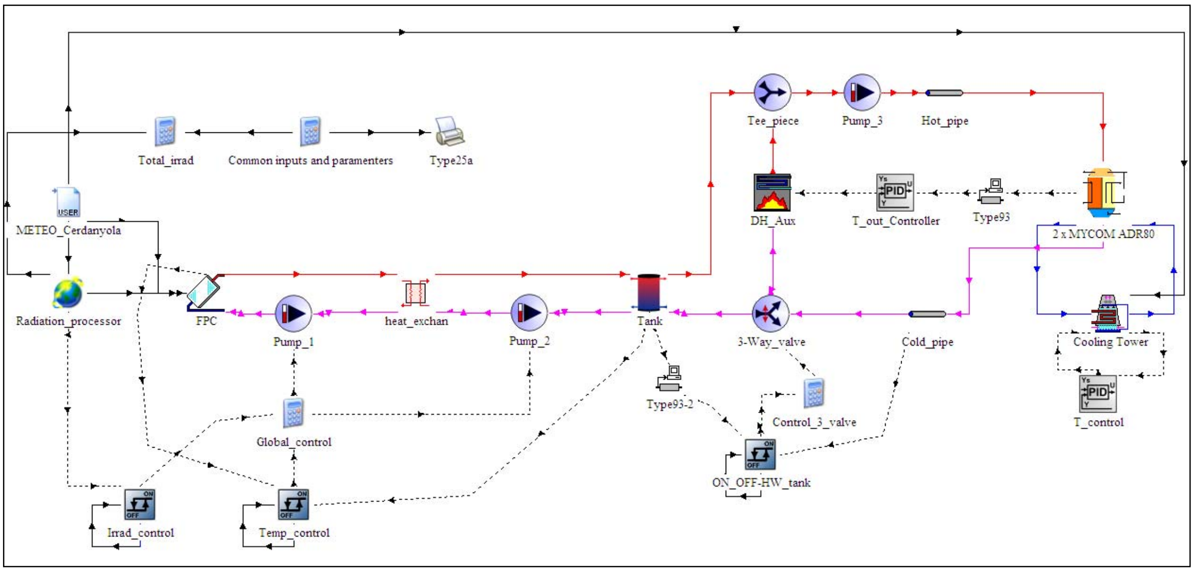

Figure 4 . Developed Trnsys model for the solar cooling plant (López-Villada et al, 2007).

The basis to compare the different alternative configurations is the sizing of the system to obtain a cooling production of 700 MWh. Although the best energy performance is obtained using ETC-CPC collectors with ad- or absorption chillers, the techno-economic evaluation clearly suggests that the best system configuration to produce the required cooling consist of a selective FPC field of 1611 m^2 with a tilt angle of 35º and using an adsorption chiller of 600 kW driven at a temperature that goes from 60 to 80ºC depending on the ambient conditions (López-Villada et al, 2007).

5. OPTIMISATION OF THE POLYGENERATION PLANT

5.1. Description of the optimisation model

Optimization of energy systems is a key issue in the design of more sustainable development models, especially in urban areas, where almost all the electrical energy is produced in remote large scale power plants, and cooling and thermal requirements are produced locally in each dwelling or building.

A literature review has been performed to study the optimisation techniques used in the field of energy supply and demand systems, with special attention to distributed energy technologies using renewables for DHC networks in residential applications (Ortiga et al, 2007). There are many models and tools for optimization at national or regional level (for large systems comprising a whole region or country) or for detailed simulations of smaller systems (a building, a power or production plant, etc). However, there are only a few applications for the optimization of intermediate systems, where the energy demand of a district is covered by one or more power plants with DHC networks. An example is presented by Söderman and Pettersson (2006), a MILP problem gives the Energy supply system structure and the optimal connection of the users, through the main previously defined DHC route. There are some commercial programs for DHC simulation like TERMIS and WinDes but do not include the energy production side optimisation.

A mathematical programming model using GAMS have been developed to propose an initial size and analyse the operational conditions and economic analysis for the polygeneration plant of the PolyCity project (figure 5). With the model the optimal size and operation of each technology is found minimizing economic costs. GAMS is an environmental programming language to solve optimisation problems of different nature choosing different types of solvers.

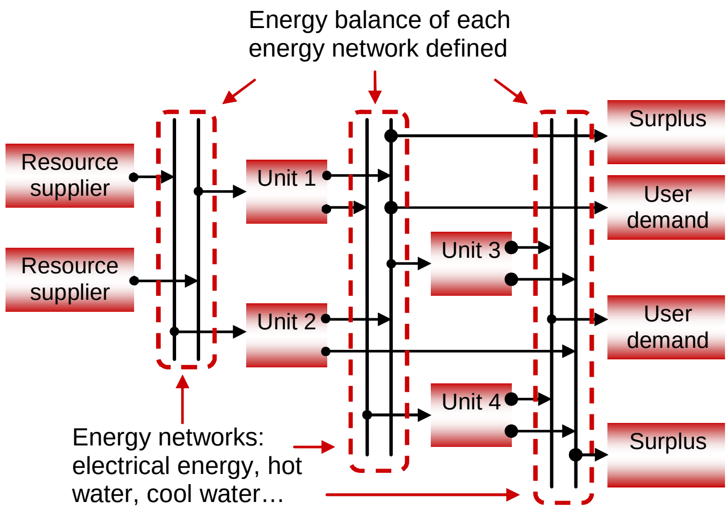

Figure 5. Structure of the model developed in GAMS.

The model has been implemented in a user friendly interface using Borland Delphi 2006 in order to make it more flexible and easy to apply in different cases and scenarios (Ortiga, 2007). The model is organized in different files, one file for each type of unit (CHP engines, SE Absorption, DE Absorption, Boilers, etc.) where the GAMS equations for each type of model (LP – linear Programming, NLP – Non-linear Programming) and unit are described, as well as some sentences with a special syntax to allow the interface to compile the GAMS model as a function of the defined superstructure and their options and properties. The user describes the superstructure of the polygeneration plant using units or items (a cogeneration engine, an absorption chiller, a cooling tower, etc.) that are connected between them and organised in a tree structure. With the information provided by the user, the interface writes the model and executes GAMS. All the results of the model such as nominal capacity, operational conditions of the units, economic and environmental parameters, etc. are displayed by the interface, in the form of graphics and tables (figure 6).

5.2. Application to the Cerdanyola project

The first useful application of the developed optimisation model in the Cerdanyola project is to find the optimal size of each type of technology included in the superstructure. In this case, there are no specific units with a given nominal capacity; so the model will find the total nominal capacity for each type of technology, without considering how many units are used.

CHP engines works always at full capacity and the evaluation of the part load operation for these units is not necessary. However, the influence of the part load operation of the simple effect absorption chiller respect to the LP model results have been evaluated.

The information for the modelling of the part load operation of the single effect chillers has been obtained from López-Villada et al. (2007). The data that have been used is:

- Capacity of the chiller (kW) as a function of the cooling water temperature (ºC) and driving temperature (ºC) for a constant chilled water temperature (7ºC).
- COP of the chiller (kW) as a function of the chiller load.

Table 1 shows the total energy consumption and energy production for all the year for the single effect absorption chillers as a function of the optimisation model used. As the nominal size of the cogeneration units results to be almost the same in LP and NLP models the available energy is the same but as a consequence of the variation of the COP with ambient conditions the total cooling production is lower in the NLP case.

Table 1 Energy consumption and production comparison

	Energy consumed [MWh/year]	Energy produced [MWh/year]
LP	18254	12437
NLP	18259	13694

Nevertheless the impact on the rest of the units is very small. On the other hand, the uncertainty of the energy demand distribution during the fifteen days periods of time resolution for the energy demand makes very difficult to know if the part load operation results are accurate. During the summer period, average COP values of around 0.7 are obtained. This could be true if the chillers work during day and night but with the current available data this hypothesis can not be evaluated.

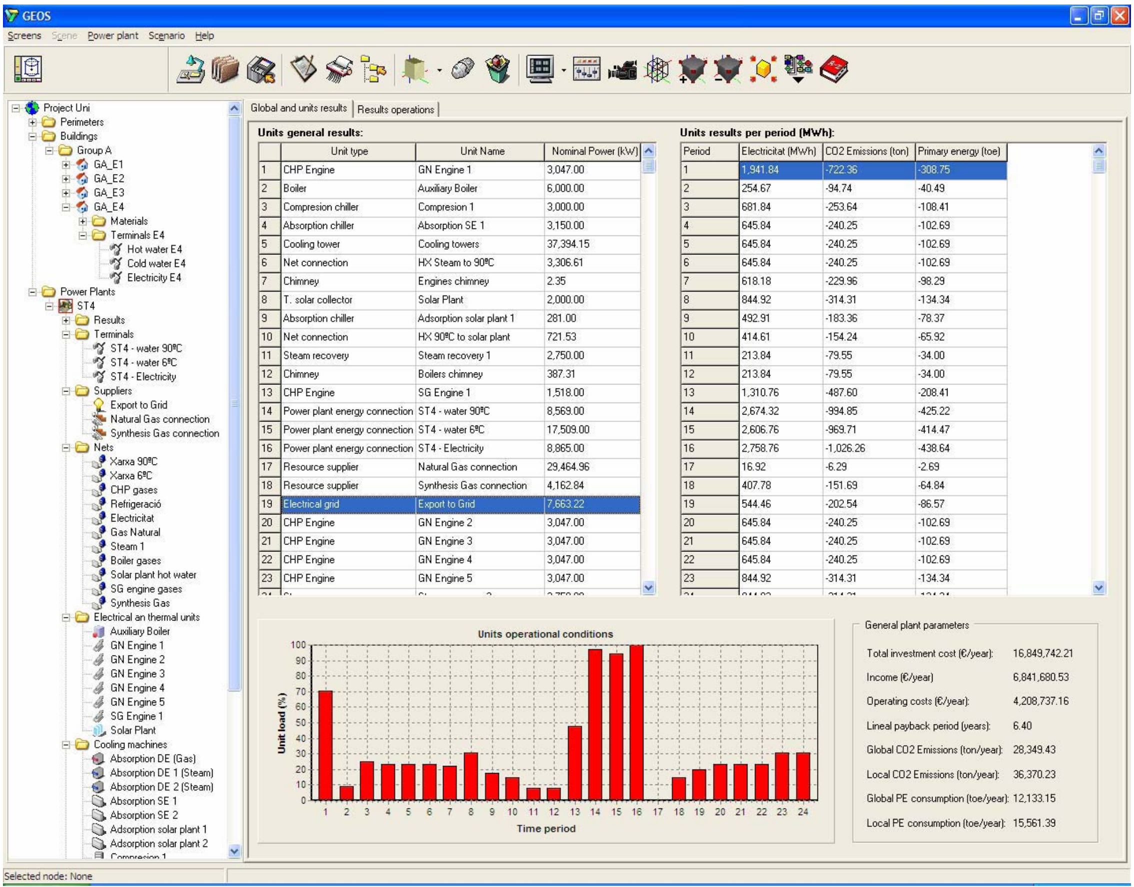

Figure 6. Screenshot of results page using the optimisation interface in development.

7. CONCLUSIONS

The integration of polygeneration systems into district heating and cooling networks (DHC) including renewable energy sources is an alternative to conventional systems that will help our communities to reduce the primary energy consumption and the emissions of pollutants.

The polygeneration plant under construction in Cerdanyola del Vallès (Spain) in the framework of the Polycity Project is expected to reduce the primary energy consumption (38,100 MWh/y) and save 7,500 ton/y of CO_2 emissions with respect to an equivalent conventional system. A mathematical programming model using

GAMS have been developed to propose an initial size and analyse the operational conditions and economic analysis for the polygeneration plant of the PolyCity project. A user friendly interface was built to make the model more flexible and easy to apply to different case studies. In the Cerdanyola project at the present level of detail with respect to the energy demand the introduction of non-linearities due to absorption cooling part load operation has not a relevant impact on the results.

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the funding of the Polycity Project by the 6th EU Framework Programme for Research and Technological Development (FP6).