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# Review of optimization models for the design of polygeneration systems in district heating and cooling networks

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**Abstract**

The current increasing energy prices and the limitation of the existing energy resources promotes the use of new energy production systems, like hybrid integrated systems (using fossil fuels and renewable energy sources) with high-energy efficiency. These integrated systems, known as polygeneration systems, produce electrical, heating and cooling at different conditions at a higher efficiency than a conventional system, and involve a wide range of technologies with several possible configurations. Sometimes the design of these systems is carried out with the aid of mathematical models that are solved and optimized minimizing the investment and operational costs, but these optimization techniques are applied frequently for industrial applications and rarely for building or district heating and cooling (DHC) applications.
The objective of this paper is to present a literature review of the optimization techniques that have been used so far for building or DHC applications. The main purpose of this review is to establish the basis for the development of an optimization tool for the synthesis and design of polygeneration systems for their use in district heating and cooling networks, that are optimized reducing their investment and operational cost. An example is presented to illustrate the application of this tool.

**Keywords:** Polygeneration systems optimization, district heating and cooling optimization

## 1. Introduction

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. According to the *Plan de Acción E4* (a strategy for energy saving and efficiency in Spain for the period 2004-2012) in the year 2000, 58.4 % of converted energy was lost due the efficiency of conversion systems and transportation losses. In tempered regions like Spain, the high use of electrical compression refrigeration units in summer, as well as electrical heating units in winter gives raise to an intensive use of the electrical network with historical demand peaks demands in winter and summer that grows year to year. The use of District Heating a  and Cooling networks (DHC) and Distributed Energy Systems (DES) represents a more reliable and sustainable alternative. Energy is produced locally and energy losses are avoided, . moreoverMoreover, the integration of several technologies with the use of renewable sources, decreases the consumption of primary energy and contaminants emissions. A more detailed discussion of centralized energy systems versus distributed energy systems can be found in Alanne and Saari [1].

## 2. DES and DHC optimization methods

The objective of this paper is to make a review of optimization techniques applied to DHC and DES applications in both residential and industrial fields. Due to the lack of previous research on optimization methodologies applied to all the considered technologies integrated in a unique energy supply system (DHC, DES and renewable energies), the review has been focused and structured according to the main topics involved: optimization techniques, DHC layout, configuration of the energy supply system, users connectivity to the network, users demand modeling, and finally, the technologies involved in the production energy system. A future result of this research will be the development of a tool that will integrate all the topics mentioned previously.

### *2.1. Optimization techniques*

The use of optimization algorithms are is widely used to find the best alternative configuration or production schedule for heat and power generating systems. The most common approach used for DES and DHC is mathematical programming, but also other methods like genetic algorithms, neural networks or fuzzy logic systems are quite extended. A general classification, a review and brief tutorial of all these techniques can be found in literature [2]

## *2.2. Multicriteria optimization*

Usually several conflicting and non-comparable criteria appear in optimization problems. The most common is economical criteria, but other criteria like emissions of contaminants (environmental criteria), product quality, safety or flexibility must be considered. Multicriteria algorithms can be applied for example to compare different power plant types [3].

## *2.3. Energy demand and energy load calculation*

Energy demand is the most important data for the simulation and optimization process. Sometimes the optimization algorithm selected will depend on the type and the frequency of the available energy demand data. The most common way to calculate load demand for individual buildings is the use of simulation programs like TRNSYS or EnergyPlus. In other cases, simulation models for energy demand calculations are developed taking into account geographical data, type of consumer, historical consumption data, and other regional specific considerations [4]. Other models use also recent load data and neural networks to improve the load estimation or to identify deviations from the expected trend and correct the energy demand prediction [5], because building simulation programs cannot take into account accurately all the possible user behaviours affecting the energy demand of the building.

## *2.4. DHC optimization and regional planning*

Examples of models including the optimization of both the production sites and the district network are scarce in the literature. An example is presented by Söderman and Pettersson [6], a MILP problem gives the DES structure and the optimal connection of the users, through the main DH previously defined route. There are some commercial programs for DHC simulation like TERMIS and WinDes. For regional planning, it has been developed TIMES has been developed, a mathematical model (MILP implemented in GAMS) that can be used on a local, regional, national or global scale [7].

## *2.5. Renewable energy sources*

Solar energy is by far, the most integrated renewable energy source in energy supply systems in urban areas. An example of their integration in a DHC network can be found in [8]. Biomass gasification for electrical and heating energy production are currently attracting a lot of interest due to their higher efficiency in comparison with direct biomass combustion. One example is the Güssing plant in Austria [9].

### 3. Future work: Application to the PolyCity case study

The future application of this review will be the development of software for the optimization of DES and DHC considering all the aspects analyzed in this review (DES, DHC, users connectivity, integration of renewable energy technologies, etc.). So farAs a first step an NLP model using GAMS has been developed to optimize the size and the operation of a Polygeneration superstructure including biomass, CHP, solar energy, absorption (simple and double effect), adsorption and compression chillers. This model has been applied to a real case for the design of a Polygeneration plant in Cerdanyola (Spain) in the framework of the Polycity project [10]. Figure 1 shows the considered plant configuration, for the final solution considered in the PolyCity project.

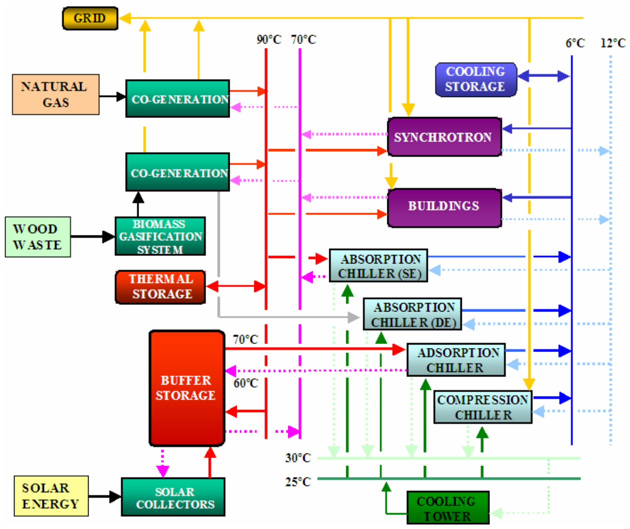


Figure 1 Example of polygeneration system to be optimized using the NLP model.

The input parameters for the model are the energy demand and costs, efficiency curves, technological operational limits, and the selection of which technologies have to be taken into account in the optimization model. Solar plant production is calculated with the solar irradiation for Barcelona (where it is located the polygeneration plant), oriented to the south and with an inclination of 30º. The efficiency equation for the selected collectors and the average number of solar daily light hours, are used to obtain the thermal energy production of the plant for each time period. The energy demand is available for periods of 15 days, so the year is divided in 24 periods. The model can be used to compare several alternatives using different technologies, for example, the optimal solution for a conventional case with boilers and compression chillers, can be compared with the optimal solution using a cogeneration or trigeneration system, with the integration of renewable energies. Table 1 shows a summary of the results comparing the conventional case with the proposed system for the PolyCity project. As shown, important savings in terms of primary energy and $CO_2$ emissions are obtained using renewable and distributed energy systems, instead of purchasing electricity from the grid and producing heat and cooling with conventional equipment.

Table 1 Summary results of the NLP model applied to the PolyCity case study.

| Summary | Conventional system | PolyCity system |
|---|---|---|
| Primary energy consumption (MWh/year) | 317,483 | 151,064 |
| Primary energy saving (%) | - | 52% |
| Primary energy from RES (MWh/year) | - | 33,007 |
| Biomass (MWh/year) | - | 30,923 |
| Solar (MWh/year) | - | 2,084 |
| % RES in consumption | - | 18% |
| $CO_2$ emissions (t/year) | 50,894 | 36,028 |
| % $CO_2$ emissions reduction | - | 29% |

The outputs of the model are which those technologies technologies that are enabled selected in the final optimal solution, the nominal size of the unit, and the operational conditions for each time slice considered. Figure 2 shows a graph of the annual operation schedule of the cooling units for the PolyCity system to fit the cooling demand. The base load is provided by the simple effect absorption chillers while the peak demand is supplied by the compression chillers. Adsorption and double effect absorption chillers work almost all the time (whenever is possible) to the maximum capacity to recover all the available solar energy and to take advantage of their higher efficiency, respectively.

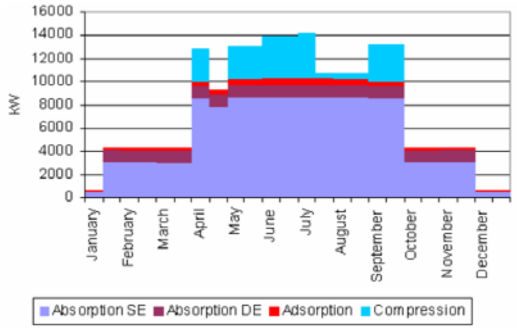


Figure 2 Cooling balance for a year in the PolyCity project.

The future application of this review will be the development of software for the optimization of DES and DHC considering all the aspects analyzed in this review (DES, DHC, users connectivity, integration of renewable energy technologies, etc.). Another tool that is under development will be used to represent a 3D scenario of the zone included in the DES and DHC that can be a single building, a street or several districts. This tool will be used for DHC routing, building energy demand analysis, user connectivity and will integrate the calculation and optimization of the DES and renewable energies.

## 4. Conclusions

Several aspects concerning the optimization of DES and DHC systems have been reviewed. The most important drawback is the determination of energy demand, and the increasing difficulty in the energy system optimization when a large number of time periods is considered. A NLP model has been developed for the optimization of a polygeneration plant with a district cooling and heating network and applied to the PolyCity case study, using fossil (natural gas) and renewable energy (solar and biomass) simultaneously with a highly variable energy demand. Respect With respect to the conventional case (purchase of electricity, thermal energy produced with boilers and the use of compression chillers for cooling demand) a reduction of 52% in primary energy consumption will beis reached, and $CO_2$ emissions will decrease 29%. The model has been used to determine the units optimum size and their load in each time slice considered.

## References

1. K. Alanne, A. Saari. Distributed energy generation and sustainable development. Renewable & Sustainable Energy Reviews. 2006, 10:539-558.
2. L. T. Biegler, I. E. Grossmann. Retrospective on optimization. Computers & Chemical Engineering. 2004, 28:1169-1192.
3. N. H. Afgan, M. G. Carvalho. Multi-criteria assessment of new and renewable energy power plants. Energy. 2002, 27:739-755.
4. E. Dotzauer. Simple model for prediction of loads in disctrict-heating systems. Applied Energy, 2002, 73:277-284.
5. R. Gao, L. H. Tsoukalas. Neural-wavelet methodology for load forecasting. Journal of Intelligent and Robotic Systems 2001, 31:149-157.
6. J. Söderman, F. Pettersson. Structural and operational optimisation of distributed energy systems. Applied Thermal Engineering, 2006, 26:1400-1408.
7. ETSAP, http://www.etsap.org/Tools/TIMES.htm.
8. J. C. Bruno, J. López, J. Ortiga, A. Coronas. Techno-economic design study of a large-scale solar cooling plant integrated in a distrct heating and cooling network. 61st ATI National Congress – International Session “Solar Heating and Cooling”. Perugia, 2006.
9. H. Hofbauer, R. Rauch. Fluidized bed gasification for biomass combined heat and power production in Güssing. Euroheat & Power/Fernwarme International. 2003, 32:50-55.
10. Polycity – Energy Networks in Sustainable Cities. Sixth Framework Programme. Concerto Programme. www.polycity.net.