Energy Urban Planning of a District in Geneva

Ana Teresa Prata Noéme

Instituto Superior Técnico – Universidade Técnica de Lisboa
Av. Rovisco Pais, 1049-001 Lisboa, Portugal

Abstract

This paper addresses the problem of district heating, which is being recognized as an important area of research. The development of a method that defines the energy conversion options that lead to the rational use of energy in a district of Geneva, Switzerland is presented.
The problem characterization is made and the models used are described. The methodology used is explained, which involves three phases: the research phase, the development of the EnerGis model (analyses the possible synergies between the resources and the services to deliver) and the development of the EASY model (process integration between the needs of the buildings and the technologies).
The case study is presented taking into account the phases referred. The results are analysed and discussed.
As final conclusion it are identified the best technology and system to be use in a district with forty five buildings in order to guarantee the energetic needs of those buildings with the best energetic efficient as possible.

Key words: energy conversion, district heating, process integration, heat pump, cogeneration, energy efficiency.

1. Introduction

In the world today, one of the most important issues is the sustainability and the sustainable development.
In this context, the reduction of CO_2 emissions is a challenge for the coming decade, especially with the implementation of the Kyoto protocol. Also the reduction of energy consumption is a requirement.
Concerning this issue district energy systems that are constituted by equipments within a network that provides energy to a set of buildings in the most efficient way, are believed to be a form to explore in order to represent an option for a sustainable development.
The goal of this work is to define the energy conversion options that lead to the rational use of energy in a district of Geneva, Switzerland. This is made by considering and comparing the available resources and the possible technologies to supply the energy services of the district. First of all, after the data collection on the buildings in study needs and on the resources available in the district area, two models are used to achieve this goal. EnerGis, the first model used, analyses the possible synergies between the resources and the services to deliver. With all the information about the requirements (composite curves) the second model EASY, can be utilized. In this model is made the process integration between the needs of the buildings and the possible technologies to use.

2. State of the Art

There are some studies in district energy systems however this issue continues to be the object of much interest among researchers.
The majority of the literature on district energy systems concerns the optimization (mainly in terms of costs) of the operation strategies of the energy conversion technologies, and/or the thermo-economic design and optimization of the energy conversion technologies.
The list of works cited here cannot be considered exhaustive, but gives an overview of the research conducted mostly about the technologies.
Ozgener et al. (2006) studied the performance of geothermal district heating

systems in Turkey, by comparing the efficiencies of two different sites.

Von Spakovsky (Weber, 2007) used mixed integer linear programming models to study the optimization of the operation of an heating and electricity plant connected to the distribution network of the Swiss Federal Institute of Technology in Lausanne (Switzerland), comprising two gas turbines and two heat pumps as well as two storage devices.

Rolfsman (Weber, 2007) studied the optimal operation strategy of a combined heat-and-power plant, maximising the production of electricity when it can be sold at peak prices, thus implementing heat storage devices to have enough heat for the district heating system when electricity prices are low and the heat-and-power plant is not running at its maximum load.

Rydstrand et al. (2004) examined the performance of humidified gas turbine cycles in district heating applications and came to the conclusion that such cycles have a potential to give much lower specific investment costs compared to combined cycles.

There are also two thesis developed at the Swiss Federal Institute of Technology in Lausanne, by Curti (1998) and Bürer (2003) that have to be mentioned. Curti developed a method to design and optimize district heating systems, following an environomic approach (economic, energetic and environmental). Bürer, on the other side, conducted research work on the potential of polygeneration energy systems to reduce the CO2 emissions linked to the residential and commercial sectors in Tokyo and Beijing, based on a mutli-criteria optimization method.

Also in the Swiss Federal Institute of Technology in Lausanne, but more recently has been developed a geographical information system to model the energy requirements of an urban area (Girardin, et al. 2008). The objective of this platform is to model in detail the energy services requirements in a specific geographic area in order to evaluate the integration of the energy conversion systems. This approach is going to be used in the present thesis.

On the works mentioned above nothing is mentioned on the network configuration. One of the reasons might be that they believe that the distribution network is anyway solved by politicians and urban planners, without involving any quantitative support. Therefore it is useless to include the design of the distribution network when studying the thermo-environomic optimization of district energy systems. This is not really the case and should be further studied as it is will be addressed along the present work.

3. Problem Characterization

In this work it is developed a model for a district heating network the more energetically efficient as possible. The district in study, named Plan-les-Ouates, is in Geneva and aggregates forty five buildings forming a quarter (see figure 3.1). The model developed is based on real data of the buildings, available information provided by a system of territorial geographic information and statistical data.

Figure 3.1 Location of the buildings in study

With this work it is intended to study the best network solution and the best system that guarantees a certain level of heating to the district. The decision is based on the analysis of the needs of the buildings, resources of the district, output variables (like exterior temperature), primary energy available and possible energy conversion technologies.

In this work are considered eight possible technologies and two systems: decentralized and centralized system. The first system is constituted by one utility for each building. The centralized system is formed by a big utility connected through a network to all the buildings. Each building has a small utility to supply the different requirements between the buildings.

The present work involves four main phases. In a first phase a data collection was performed. This includes the needs of the buildings and the resources available in the area in study.

With this data analysis it was possible to consider and measured the energy services (heat, cold, hot water and electricity) and

the energy resources available in the district considered (water, solar energy, geothermal energy, and biomass). This analysis was made in a second phase of the work where a model previously developed for the Geneva canton, EnerGis (Weber, et al. November 2007), was adapted and generalised to threat the data for the case studied along this work.
With the results of the energetic model (EnerGis), a third phase was performed. This involves the process integration and its optimization under the tool EASY. In this all pointed technologies were explored as a way to understand what would be the more efficient solution for the case study.
After the third phase the work is completed by performing an investment analysis of the technologies studied (fourth phase).

4. Methodology

As referred above the work presented in this paper involved four main phases. Two different models are used which are implemented in two software tools: EnerGis and EASY. These are described below. Also an investment analysis is performed and its characteristics are detailed below.

4.1 EnerGis Tool

As referred above, EnerGis is a software tool built on a model. This considers a strategic plan for the development of the technologies used for the thermal needs of a certain area. It analyses the possible synergies between the resources and the services to deliver. Its objective is to establish a matching between the required energetic services in a certain geographic area and the available resources in the same area. For that it is important to analyse the performances of the energy conversion advanced systems that use in an efficient way the resources of that zone.
Therefore, the model simulates the scenarios for the needs satisfactions considering the local resources and the existing conversion technologies. The model was applied to the Geneva canton and considers a division by sectors which were then considered for different periods of the year (winter, summer, mid-season and design case. Weber, November 2007). In this way, it was possible to evaluate what are the most promising resources for each sector depending on the needs and on the existent external variables.
The method used to build this EnerGis tool is based on the energetic integrations principles. The assessment of the thermal needs represented by a composite curve, allows the prediction of the energetic services to provide and highlight for opportunities of energy revalorization.

4.2 EnerGis Model

Some of the model data is obtained from a geographic information system. The buildings in the sectors are characterized by its geometric specification, area location as well as building type and year of construction. Different kinds of buildings are considered namely residential, commercial, administrative, health, educational, hotels amongst others.
The methodology used by EnerGis is as follows:

- Identification of the energy spent indices;
- Categorization of the area of construction;
- Modelling of the energetic needs during time;
- Construction of the needs composite curve (Q-T diagrams).

The proposed model depends on the exterior temperature and satisfies the thermal energy in a building. The modelling of the thermal power required is based on the energetic signature theory. The energy signature theory states that there is a linear relation between outdoor temperature and building consumption. Thus, the temperature levels are obtained by a modelling of the curves of heating/cooling.
The multi-periodic analysis is made in 3 seasons:

- Winter: of November 15 to March 15
- Summer: of June 1 to August 31
- Mi-season: the time remainder.

4.2 EnerGis and its application to Geneva Canton

The EnerGis as referred above was only developed for the Geneva canton. With this tool is possible, from data of the *Service Cantonale de l'Énergie* (buildings characteristic and respective consumption), to determine the statistic values on the

surface consumptions of the buildings in function of its type of affectation (the type of buildings depending on the construction year). With this intention, the Geneva canton was divided in 475 sub-sectors, areas where construction was allotted (as well as the proportion of each affectation). Thus, it was possible to determine the consumption for each defined zone. This can be done for different temperature conditions. At the moment EnerGis considers: summer, winter, mid-season and one day of extreme cold (design case) with the temperature of -6ºC.
It is important to notice that EnerGis model is done for all sectors of the Geneva canton with statistical data. One part of this work will be therefore to adapt this model to the data and characteristics of real building within a defined area in the Geneva district (Plan-les-Ouates). The resources of the area and the requirements of the buildings are inputs to this adaptation. From this new model results the representation of the needs of the buildings represented in composite curves.
The next step of the work is the process integration between the needs and characteristics of the buildings and the technologies available. The results from EnerGis are the inputs in EASY (Energy Analysis and Synthesis of Industrial Processes).

4.3 EASY Tool

EASY is an interactive energy integration tool that allows the calculation of the optimal use of energy in industrial processes. It has been developed to solve process integration problems where the flow rate of streams has to be optimised.
The Easy tool receives as an input the composite curves, a list of streams and a list of utilities that come from EnerGis, as explained above. With these inputs and with the different technologies implemented in EASY, it is obtained as output information about the best technology to choose.
The main variables for almost all the technologies are the input and output temperatures of the network and the difference between maximum temperature of heating and the evaporation temperature. Some work has been done to implement different technologies in the EASY tool. These are respectively: a water heat pump, an air heat pump, a geothermal heat pump, cogeneration with a gas engine and cogeneration with biomass.
The study developed also considered the analysis of a centralized system and a decentralized system with the integration of all mentioned technologies in such a way that allows for the choice of the best solution.

4.5 Investment Analysis

After the analysis on the technical results of this case study with EASY tool, an investment analysis is important so as to complete the results. Thus, it is possible to have a more consistent conclusion about this work.
Based on the bibliography studied is assumed that the life time of the network is sixty years and the life time of each technology is twenty years. Thus, the investment analysis is made for the time period of sixty years. The Net Present Value (NPV) and the benefit-cost ratio (RBC) are calculated as well.
It is considered, for the investment cost the cost of each technology and the cost of the network for the centralized system.
The investment cost is calculated for each technology with the formulas proposed by Grandjean (2006).
The network cost is calculated in EnerGis. The input variables are the inlet and outlet temperatures [K] and the heat load [MW] of the network, the operating time [h/year], the surface of the district [Km^2] and the number of buildings.
It is important to refer that the network costs calculation is an approximation since that the surface of the district is just an approximation.
The used criteria for the profitability analysis are the Net Present Value (NPV) and the benefit-cost ratio (RBC) so as to understand what is the best solution.
NPV is the difference between the benefits and the costs that characterize an investment, after an updated with an actualization fee well chosen. The NPV is calculated for each technology and for each system, centralized and decentralized. The formula used is represented below.

$$NPV = \sum_{t=1}^{n} \frac{Values\ t}{(1+i)^t} \tag{1}$$

where *i,* represents a tax of actualization. In this case it was used, as an assumption, 3%. The *Values* represent the cash-flow balance between the costs and the profit. The costs are constituted by the investment cost, and the exploitation costs (it was assumed that the exploitation costs were 3% of the investment cost as it is used in similar systems).

The benefit-cost ratio (RBC) it is another way to measure the profitability of an investment. In this case it is express by the quotient between the benefits and the costs after an actualization in a convenient tax.
The formula used to calculate this ratio is the following.

$$RBC = \frac{\sum_{t=0}^{n}(Bt - Ct)(1+i)^{-t}}{\sum_{t=0}^{n} It\,(1+i)^{-t}} \qquad (2)$$

where,

- *Bt* represents the profit. It is the same profit used for the NPV calculation.
- *Ct* represents the exploitation costs (3% of the investment costs).
- *It* represents the investment cost.
- The tax used is represented by *i* (3%).

5. Case Study

The main objective of this work, as described above, is to define the energy conversion options in an area of Geneva (Plan-les-Ouates) in order to use energy in a rational way. Thus, to achieve this objective, is necessary to evaluate the available resources and study possible technologies so as to supply energy services in the district. Using the methodology described above, the case study is undertaken.

5.1 Resources

Different type of resources can be analysed: geothermal, water, biomass and air resources. Concerning the geothermal resources there is no opportunity to use them since their use in this commune is forbidden. Despite this, it is going to be done the associated study in order to analyse if this would be or not a good option in energetic terms.

In terms of water, the Geneva Lake is not very close to this commune, but Plan-les-Ouates is near to important rivers in the Geneva canton: L'Aire, approximately 5 Km, and L'Arve, approximately 3,5Km. Thus, there is a great opportunity to pump water from the closest river to use as a resource in this case study.
In terms of biomass the forest covers approximately 3.5% of the surface of the commune. Thus, maybe it is possible to use biomass in the heating network of this district. However, the production of forest on the communal territory is insufficient to promote large scale biomass energy within the commune. The possibility to bring wood from other communes to promote the biomass energy in a bigger scale is therefore a hypothesis to be considered.
Relatively to the air in Plan-les-Ouates it is considered to be good so it appears as a great resource to use in this study.

5.2 EnerGis Model Application

In order to obtain the needs of the region in study and how this can be supplied by the resources, the geographical area data was introduced in the EnerGis model. This is defined along three files: the Energis file (excel file), the needs file (shape file, created in ArcGis) and the resources file (shape file, created in ArcGis).
Energis file has all the information about each type of building and all the variables that the model needs to make all the calculations. In the original EnerGis model, each building is characterized depending on its category, year of construction and type of affectation.
Depending on the year of construction, the categories are classified by residence, administration, commerce, industry, education, health, hotels and others with more than one category associated to a year of construction and to a renewed or not renewed building. Consequently, for each type of category with all the associations, there is a different name (e.g. Resid2, Resid6, Comm2, Comm4, Sante1, Hotel3 etc).
In the needs file are represented the characteristics of the buildings, being the most relevant ones the category, the heat consumption and the electricity consumption.
Finally, the resources file represents all the resources availability.

For the last two files and by using the ArcGis software it is possible to obtain the geographical position of the buildings.
In the current case study, there are just three types of categories in this group of buildings: Resid2, Resid4, Comm2 and Comm4. The most part of the buildings are residence buildings and there are some for activities. There are no renewed buildings. The data required was some obtained from the *Service Cantonal de l'Énergie* and all the remaining values are statistical obtained and calculated by the EnerGis model.
The most important results from EnerGis are the composite curves of each building and the global composite curve. This graphics represents the needs of the buildings and are the main input of EASY tool.

5.2 EASY Model Application

In order to obtain the final result, the EASY tool is used. This tool permits the analysis between the needs and the technologies available.
As explained above, the most important results from EnerGis model are the composite curves (diagram T (temperature) – Q (heat)) for each building and the global composite curve.
The composite curves for each building are the input of the EASY model. From this diagram is possible to define the list of streams and the list of utilities in the network.
Two different network systems were analysed as a form to fulfil the heat requirements of the commune. These are respectively a centralized and a decentralized system. These two systems will be compared to see what the most efficient one is in this case.
After analysing all the available resources in the Geneva canton and in the commune, different technologies are analysed within the EASY model. These were programmed into the software with all the required data. The technologies considered are:

- Water heat pump
- Air heat pump
- Geothermal heat pump
- Cogeneration with gas engine
- Cogeneration with biomass

For all the technologies it was defined the power, or the electricity needed, the operating cost and the investment cost of the respective resource. Also a factor that translates the equipment capacity is considered. This is denoted as FACMUL.
For all the technologies the information about this costs and the FACMUL factor were given by the Mechanical Department (LENI) in EPFL were this project was developed.

6. Case-Study Results

The results obtained for two different systems: centralized and decentralized systems are described below and shown in tables 6.1 - 6.4.
First of all, for both systems is analysed the technical results, the EASY results. Taken this as basis an investment analysis to complete the results analysis is performed.

Table 6.1 Technologies characterization for centralized system in winter

Technology	Resource Temp. (ºC)	Elec./Fuel consump. (KW)	Operating Cost (MEuro/Winter)
Water HP	5	540,7	0.030
Air HP	1	614,7	0.035
Class. Geo. HP	2	577,6	0.032
Ground Water HP	11	539,8	0.027
Geostaructure HP	8	539,9	0.029
Cog. Gas engine	10	3550,2	0.041
Cog. biomass	10	3550,2	0.026

Table 6.2 COP representation for the centralized system

Technology	Annual COP
Water HP	2,839
Air HP	2,671
Class. Geo. HP	2,644
Ground Water HP	2,841
Geostaructure HP	2,840
Cog. Gas engine	1,546
Cog. biomass	1,546

Table 6.3 Technologies characterization for decentralized system in winter

Technology	Resource Temp. (ºC)	Elec./Fuel consump. (KW)	Operating Cost (MEuro/Winter)
Water HP	5	21,46	0,00157
Air HP	1	22,80	0,00167
Class. Geo. HP	2	22,51	0,00164
Cog. Gas engine	10	27,87	0,00153
Cog. biomass	10	64,91	0,000938

Table 6.4 COP representation for the decentralized system

Technology	Annual COP
Water HP	2,80
Air HP	2,70
Class. Geo. HP	2,48
Cog. Gas engine	3,76
Cog. biomass	1,72

6.1 Centralized System

Analysing the results for the centralized system (see table 6.1) is possible to conclude on which technology is the best one to use.
The air heat pump, classic geothermal heat pump and the cogeneration system are not the best solutions since they have the highest values for electricity/fuel consumption. Relatively to the operation costs, the cogeneration with biomass can be a good solution since has a lower value. Once more, the air heat pump and the cogeneration with a gas engine are not good solutions in terms of operating costs.
The lower is the resource temperature more heat is needed to heat up the fluid. So, these values can be explained through the resource temperatures that in the case of these technologies are lower.

Relatively to the COP (see table 6.2), since the highest COP is the best one, the results are coherent to the ones explained above. The COP depends on the electricity consumption and in the heat load. The water heat pump, the ground water heat pump and the geostructure heat pump have the best COP.

The air heat pump is a special case. The heat exchange it is more efficient with a fluid than with a gas. Thus, it is difficult to compare the air heat pump in a linear way. It is difficult to precise the outside temperature because it has a lot of variations during one season. In this way, the air heat pump will be compared in a linear way but it is important to take into account that the results about this technology should be more carefully analysed.

Thus, from the results presented for the centralized system, the best solutions are the water heat pump, ground water heat pump and cogeneration with biomass.

6.2 Decentralized System

Analysing all the studied results for the decentralized system is possible to conclude which technology is the best one to use in this case (see table 6.3).
The air heat pump and the cogeneration system are not the best solutions since they have the highest values for electricity/fuel consumption. Relatively to the operation costs, the cogeneration with biomass can be a good solution since has a lower value. Once more, the air heat pump and the geothermal heat pump are not good solutions in terms of operating costs.

Relatively to the COP (see table 6.4), the cogeneration with gas engine, water heat pump and air heat pump have the best COP.
The cogeneration with a gas engine has the best COP and a very competitive operating cost although the fuel consumption is high.

The air heat pump appears as a special case, as explained in the decentralized case.

Thus, from the results presented for the centralized system, and taking into account the three variables (electricity/fuel consumption, operating cost and COP), the best solutions might be water heat pump and cogeneration with gas engine.

6.3 Investment Results

In this section it is considered the technical results described above for the centralized and decentralized system and the investment analysis made after this technical approach.

It is possible to conclude, considering the NPV analysis, that for the centralized system the best technologies are the air heat pump and the ground water geothermal heat pump. In the decentralize case, the water heat pump is the best technology.
Considering now the RBC analysis (see table 6.5), the air heat pump and the ground water geothermal heat pump in the centralized system are the best solutions for this case study. Relatively to the decentralized system, the water heat pump is the best solution.

Table 6.5 Benefit-Cost Ratio (RBC)

Technology / System	RBC
Water Heat Pump / Decentralized System	1,94
Air Heat Pump / Centralized System	22,90
Ground Water Heat Pump / Centralized System	8,95

In the decentralize case, the benefit-cost ratio is 1,94 as shown in the table above. This means that the profits of this investment are 94% bigger than the costs therefore there is a margin of 94%. For the project to have no profits, the costs should be 94% higher. Thus, the investment for the centralize system it worsted. It is important to notice that these results are consistent with the results before of the investment analysis.
For the centralized case it is done the RBC calculations for the air heat pump and ground water heat pump because are the best solutions in the results before the investment analysis and are the two that have the best NPV. Between the two solution, with an examination of the RBC is possible to conclude that, for the centralized system, the ground water geothermal heat pump is the best solution.

7. Conclusion

The main conclusion of this work is that the best system to provide the energy services to the buildings in study relies on the decentralized system using as technology a water heat pump.
In this work there were some assumptions made and some statistic data considered. Therefore the results are not fully representative of the real situation and further work need to be done to overcame this disadvantage.
The models used and developed in this work are still in a research phase. In this way, there is a lot of possible and interesting future work to be developed:

- Further study should be made for the centralized system where the technologies used at the building level should be considered, aspects that was not taken into account at the present study but is definitely important to be analysed.
- The models developed were case-study oriented therefore a generalisation of the models to adapt them to any district should be made in the future.
- It would be also very interesting to analyse changes in the network temperature. For example develop the same calculations with a network temperature of 80ºC and compare the results obtained with the present results so as to analyse the influence of the temperature in the energetic efficiency. Also it would be interesting to compare the energy consumption after the implementation of this new solution and make the same comparison as the one made in chapter five.
- The cooling in the buildings is a very important issue in some countries, even for Switzerland that is a cold country in most part of the year. It would be interesting to create a model that joins the heating and the cooling of the buildings so as to have an energetic efficiency for different situations.
- The solar energy was referred in this work as a very important renewable energy to be used. This was not explored however in the

present work and should not be neglected in the future.

References

Bürer, M. (2003). *Multi-criteria optimization and project-based analysis of integrated energy systems for more sustainable urban areas.* PhD Thesis, EPFL. Lausanne, Switzerland.

Curti, V. (1998). *Modélisation et optimisation environomiques de systémes de chauffage urbain alimentés par pompe à chaleur*. PhD Thesis, EPFL. Lausanne, Switzerland.

Girardin L.; M. Dubuis; N. Darbellay; F. Marechal & D. Favrat (2008). *EnerGis: A geographical information based system for the evaluation of integrated energy conversion systems in urban areas.* Report. EPFL. Lausanne, Switzerland.

Grandjean Y. (2006). Recherche et validation d'une method de dimensionnement pour des systems PAC-CCF. Master Thesis, EPFL, Lausanne, Switzerland

L. Ozgener; A. Hepbasli & I. Dincer (2006). *Performance investigation of two geothermal district heating systems for building applications: Energy analysis. Energy and Buildings.*

Rydstrand, M.C.; M.O. Westermark & M.A. Barlett (2004). *An analysis of the efficiency and economy of humidified gas turbines in district heating applications.*

Weber, C.; L. Girardin; M. Dubuis; F. Maréchal & D. Favrat, (2007). Stratégie thermique pour le canton de Genève: réseau de distribuition de chaleur et climatisation. Report, EPFL, Lausanne, Switzerland.

Weber, C. (2007). *Development of a method to design and optimize district energy systems*. PhD Thesis. Ecole Polytechnique Fédérale de Lausanne (EPFL). Lausanne, Switzerland.