CHAPTER 1: Introduction

1.1. Introduction of the topic

During the last three centuries, the industrialization of every country in the world is essentially based on combustion of coal and hydrocarbons. The highest standards of quality of life for more advanced countries, has led to a strong dependence and consumption of these energy sources.

Now in the 21st century, it is time to consider the future of energy considering new solutions. With the countdown to the existence of petrol, humans are increasingly aware of the connection we have with nature. We must take nature into consideration when finding energy solutions. After learning to think so, the world poses a future driven by renewable energies. The vision of a sustainable world must show us the way to all possible solutions.

On the other hand, we must not forget the problems caused by the energy dependence. After the oil crisis of 1974, consumer countries diversified their sources of generation and incorporated new technologies in production.

Energy consumption (per person) has been increasing exponentially in these last three hundred years while the world population has been growing at the same time.

The solar radiation that the Earth receives is from 15 to 20 times the total energy contained in all fossil fuel reserves in the world. The 0.005% share of the annual radiation would be sufficient to provide all the energy consumed by man.

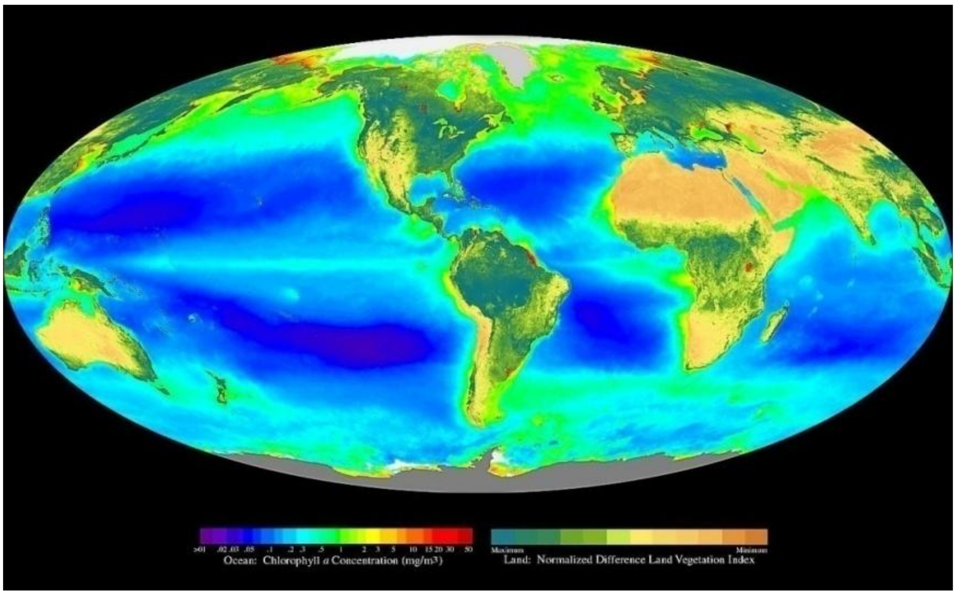


FIGURE 1. Provided by the SeaWiFS Project, NASA/Goddard SFC.

Since the beginning of the human history, biomass has been an essential power source for humans. With the advent of fossil fuels, this energy resource lost its importance in the industrial world.

Biomass is the only renewable energy that can be converted into gaseous, liquid or solid fuels by means of well-known conversion technologies. Accordingly this universal renewable energy carrier can be used in a widespread field of applications in the energy sector. Already today it is possible to provide bioenergy carriers for the entire range of energy-demanding applications, from stationary heat and power supply to the fuelling of mobile applications for transport and traffic.

Traditionally we have thought of biomass as being essentially a free resource available in unlimited quantities. However, in recent years, concerns about the potential of the world's agricultural sector to produce sufficient quantities of food for the growing world population and the dangers of diverting a portion of our agricultural production capacity to non-food uses is changing the image of biomass as a free and unlimited resource.

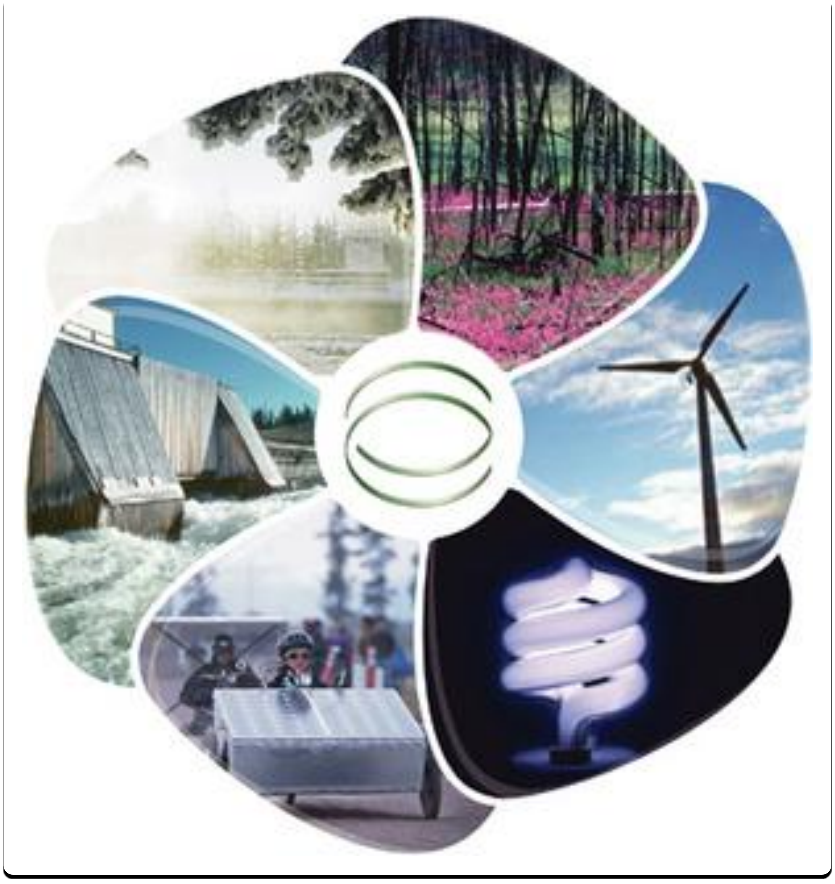


FIGURE 2. Renewable energies collage. Fuente: Business Standard (OFECOMES) 20/01/2010.

1.2. Objectives

The **main objective** of this thesis is: the technical and economic assessment of a biomass plant with a combined cycle of heating and cooling, located in Catalonia. The thesis is based on a real case, the biomass plant of Molins de Rei, located in Catalonia. The objective is, to add the cooling process to that plant. Because of that, it is necessary to add a hot driven absorption chiller, for the cooling production, and also check and fix all the changes that the net distribution needs.

The thesis is divided into the next chapters:

CHAPTER 1: Beginning with a global overview of the biomass as an **introduction.**

CHAPTER 2: This chapter speaks about the local characteristics, concerning **the current status of biomass** and renewable energies **in Catalonia**.

CHAPTER 3: This chapter aims to analyse the characteristics of heating and cooling systems about **cogeneration and trigeneration with biomass.**

CHAPTER 4: This chapter explains the current system of **the plant of Molins de Rei**. Based on the current data of the original system. Supplying heating and hot water to 700 homes.

CHAPTER 5: This chapter of the thesis aims to study the changes and additions needed for the system, in order to **add the cooling** into our real case, the plant of Molins de Rei.

CHAPTER 6: This last chapter explains the **conclusion of the results**, in two ways, one way about the technical and economical feasibility, and other way explaining the advantages and disadvantages of the project.

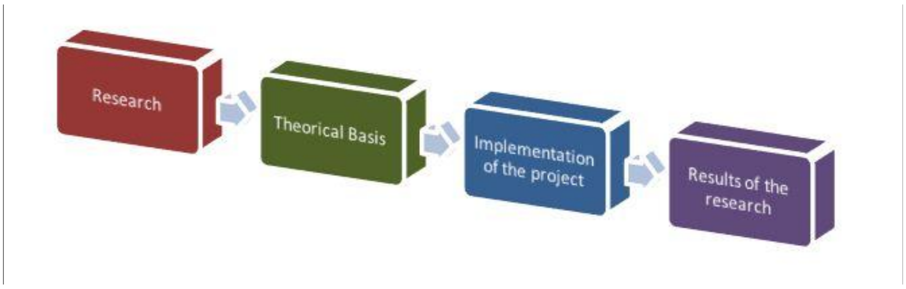


FIGURE 3. Explains graphically the way of work during the thesis project.

1.3. European Union

The European Union has committed to reducing greenhouse gases by at least 20 per cent compared to the 1990 level by 2020. The European Union has also offered to commit to a 30 per cent reduction if other developed countries agree to join in. By 2020, renewable energy should account for 20 per cent of the final energy consumption.

1.3.1. Targets

- The targets are the following:

  - 20% reduction of greenhouse gas [GHG] emissions
  - 20% renewables share in the energy mix
  - 20% energy efficiency improvement

Renewable energy sources are important for reducing carbon dioxide (CO_2) emissions and for ensuring the security of energy supplies.

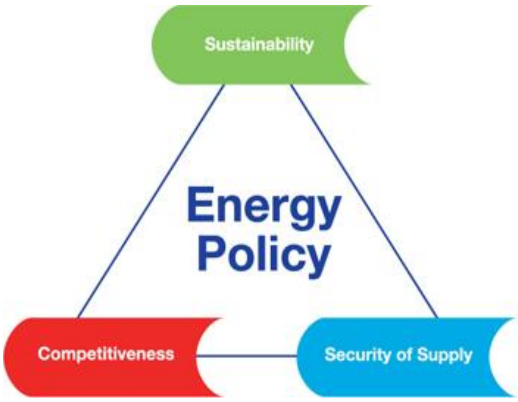


FIGURE 4. Energy Policy process. Source: European Petroleum Industry Association Publication.

EUROPEAN ENERGY POLICY is part of the process towards low-carbon emissions, in which process the EU is expected to play a leading role.

In this process already underway, there are two new factors that must be taken into account: the Treaty of Lisbon and the post-Kyoto process derived from the recent Summit in Copenhagen.

The Treaty of Lisbon: As the preamble states, the purpose of the treaty is "to complete the process started by the Treaty of Amsterdam (socioeconomic standards, broader immigration and civil judicial oversight, protection and enforcement of human rights, and an increase in the power of the European Parliament) and by the Treaty of Nice (largely preparation for the admission of new members from eastern Europe, adjustments to the power of the Commission, and adjustments to voting rules to allow easier passage of laws), with a view to enhancing the efficiency and democratic legitimacy of the Union and to improving the coherence of its action."

FIGURE 5. EU LTP. Source: Elsebeth Nielsen, EU 2008.

The Copenhagen Summit: This was a United Nations conference where delegations from 192 countries attempted to form a new global agreement to curb their carbon emissions. The objective was to forge a successor to the Kyoto protocol or treaty, and a continuation of the carbon market beyond 2012 when the current provisions of the treaty expire.

This meeting was also known as COP15 which stands for 15th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC).

FIGURE 6. Opening ceremony of the UN climate change conference in Copenhagen. Photograph: Miguel Villagran/Getty Images.

The main issues still remain essentially unchanged until now, turning on the three pillars of competitiveness, sustainability and security supply, but two additional dimensions must be considered: First, the international economic crisis and risk to finance this new energy model, and secondly, the new powers in foreign affairs established by the Treaty.

Energy policy actions undertaken within the EU for three recent years were set by the European Council of 2007. Successes have been achieved with the adoption of energy and climate package (known as the "20-20-20") or continue to develop domestic energy market. Virtually all measures that were contained in the previous Plan have already been taken by the community.

Therefore, the Strategic Review on 2nd November 2008 is considered by Ministers as the basis on which to build the next Plan of Action. While the Plan above placed the weight on sustainability and the internal market, the Member States agree that this new plan should focus on security supply and development of energy technologies.

In addition, other major energy issues that are on the table, and they need to be addressed immediately:

- The revised Action Plan for Energy Efficiency.
- The new European Security and Infrastructure.
- Funding for low carbon technologies as the basis for development the SET Plan.

These issues are in line with the creation of a more competitive economy, sustainable and interconnected, as stated in the recent consultation document "EU 2020 "adopted by the European Commission. Although the third of these elements has been the subject of a Commission communication, the other two require prompt proposed by the latter.

1.3.2. Energy policy guidelines

Here is the review of the energy policy guidelines, those that need special attention in the coming years.

- Internal Market

- Sustainability

- Security of supply

- Foreign policy

The targets for 2020 are only one step after Kyoto: The European Union has declared its goal to reduce greenhouse gas emissions by 60-80 per cent by 2050. To achieve this demanding goal, a combination of several actions is needed and the role of renewable energy must become even more significant.

1.3.3. Renewable index, November 2010

This table below shows the refreshed information of the renewable energies index in a global scale:

TABLE 1. All renewable energies index, November 2010.
Source: Ernst&Young analysis.

All renewables index at November 2010

Rank[1]	Country	All renewables	Wind index	Onshore wind	Offshore wind	Solar index	Solar PV	Solar CSP	Biomass/ other	Geo- thermal	Infra- structure[2]
1 (1)	China	71	76	79	69	60	67	40	58	51	76
2 (2)	US[3]	66	66	70	56	72	70	75	61	67	60
3 (3)	Germany	63	66	63	73	54	65	22	63	54	62
3 (4)	India	63	64	71	42	67	68	63	58	45	65
5 (5)	UK	62	68	64	79	40	54	0	59	38	71
6 (5)	Italy	61	62	65	53	65	67	59	56	65	67
7 (7)	France	58	60	62	57	52	62	24	59	36	62
8 (8)	Spain	56	56	61	42	64	62	69	50	33	55
9 (9)	Canada	54	60	65	46	34	46	0	49	34	62
10 (10)	Portugal	52	55	59	42	49	58	22	45	33	57
11 (10)	Ireland	51	58	58	57	26	36	0	48	28	61
12 (14)	Sweden	50	54	54	53	32	44	0	55	34	53
12 (12)	Greece	50	52	56	41	55	60	41	41	32	52
12 (12)	Australia	50	50	53	41	54	56	46	45	59	53
15 (19)	Japan	48	48	50	41	54	64	27	39	43	57
16 (15)	Netherlands	47	53	51	57	34	47	0	40	21	43
16 (16)	Poland	47	52	56	42	32	43	0	42	23	47
18 (16)	Brazil	46	47	52	35	41	46	30	49	22	46
18 (16)	Belgium	46	52	50	57	31	42	0	39	28	52
18 (na)	South Korea	46	47	46	51	46	53	28	41	35	43
21 (20)	Denmark	44	47	44	56	29	40	0	45	32	51
22 (na)	Romania	43	46	48	38	32	44	0	43	38	43
22 (na)	Egypt	43	44	47	35	48	47	50	37	27	40
22 (21)	Norway	43	47	48	45	22	30	0	44	30	48
25 (na)	Mexico	42	43	43	41	45	46	39	38	54	38
25 (22)	New Zealand	42	47	51	36	24	32	0	34	50	45
27 (24)	South Africa	41	43	46	35	37	35	45	35	32	43
28 (23)	Turkey	40	42	45	34	38	42	27	35	42	41
28 (25)	Austria[4]	40	38	47	0[4]	40	54	0	49	34	52
30 (27)	Finland	38	41	42	36	20	27	0	50	24	40

Source: Ernst & Young analysis

Investors and developers of renewable energies and cleantech companies could feel safety as the GRAPHIC X shows, because it is a market here to stay. However, the changing and shifting regulatory environments, intense competition and upheavals in a still highly volatile global economy make for a treacherous path and players need to be constantly shifting strategies and investment targets on a global scale.

1.4. New opportunities for industry

Demand for bioenergy, biofuels, renewable biomass based chemicals, new fibre products and other new biobased products is increasing to replace the use of fossil raw materials. The profitability of new biomass products can be increased by integrating the manufacturing of several products into the same unit, biorefinery.

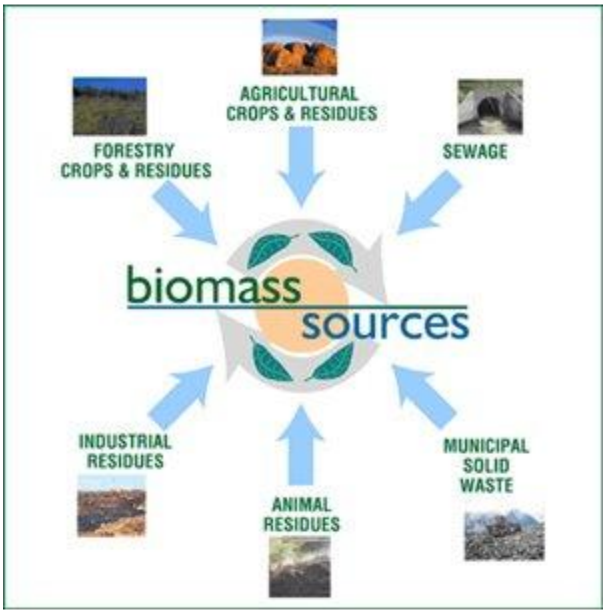


FIGURE 7. Biomass sources. Source: Natural Resources Canada

According to Antonio Gonzalo, of AVEBIOM:

-"The Spanish Association of Biomass Energy Recovery, presented several case studies of bioenergy in Spain and Europe, which show the diversity of products and technologies capable of creating jobs andenergy solutions of all kinds.

An outstanding example is the Austrian town of Guessing, which has gone from being a depressed region, utterly dependent on fossil fuels to produce all the energy it needs and even export it to other regions. Guessing is nowadays, a center of business location because of the stability of energy prices. Güssing has 8 MW of district heating and a gasification plant of 2 MW. The plant is obtaining biogas using electricity, heat for district heating, synthesis gas and methane to produce biodiesel and other products. This is what is known as bio-refineries. The plant is directly employing **1100 people** in a population of fewer than 30,000 inhabitants.

Other examples are the two cases of central heating with biomass in Spain. The first one is located in Oviedo. There is 2 MW to heat 422 homes. This plant is saving more than 100,000 euros per year. The second one is located in Ultzama, Navarra. There is 700 kW to heat the municipal buildings. The buildings are located within a radius of 1 km. Ultzama and other nearby towns are absolutely convinced of the advantages of bioenergy and are embarking on more projects. For example, there is a biogas plant, with a capacity of 500 kW.

According to Javier Diaz, President of AVEBIOM:

-"Stressed the importance of job creation with biomass, which is **135 jobs** per 10,000 residents, adding that Spain has to take seriously the substitution of biomass instead diesel and natural gas.

Other countries like Sweden and Finland produce solid biofuels (wood chips and pellets) over 30% of the energy consumed: in the case of Sweden, 2% more than that generated with fossil fuels (29%)."-

AVEBIOM proposes savings of 3,500 to 5,000 million euros in oil and gas imports also generate over **35,000 direct and permanent jobs**, with the installation of 325,000 biomass boiler.

Twelve months ago, in 2010, the price of a barrel of oil was $70, now it is surpassed $110. If we do a quick count, those $40 puts increase by 24,000 billion, a bill that Spain pays to other countries for the supplies. The Deputy Prime Minister, pointed out that for every $10 that raises the price of a barrel of crude oil, Spain spends 6,000 million more per year, which goes to other countries, leaving the value added outside Spain, and maintaining a heavy burden on the citizens.

AVEBIOM, COSE, ASEMFO, ADABE, APROPELLETS, USSE, AEBIOM, AIEL, EPC and WBA decided in Valladolid, 27 de octubre de 2010 to generate more jobs, express the opportunity offered by the forest bioenergy to create **594,000 jobs** saving CO_2 emissions and help lower energy bills in Spain and its citizens, ensuring sustainable resource management of forests.

CHAPTER 2: Current status of Biomass in Catalonia

2.1. Location and size

Catalonia is located on the west coast of the Mediterranean, north-east of the Iberian peninsula and Spain, on the border with France.

This position on the European continent and the Mediterranean is significant if we understand the historical and current events, and understand the role played Catalonia throughout the centuries since ancient times.

FIGURE 8. Catalonia location. Source: http://www.vegueries.com/geografia/mapasituacionESP.asp

Catalonia covers an area of approximately 32,000 km with its own governing body, the Generalitat of Catalunya, it is one of Spain’s autonomous communities. To the east is the Mediterranean, to the north are the borders with France and Andorra, and to the west are the autonomous communities of Aragon and Valencia. This strategic position has helped to foster close relations with the other Mediterranean countries as well as with continental Europe.

Catalonia has varied altitude between plains and several very mountainous regions. This provides Catalonia with a wide range of bioclimatic habitats.

Catalonia has the following limits:

- Land boundaries: 707 km
- Maritime boundaries: 580 km
- Total limits: 1.287 km
- Catalonia has a total area of 31,930 km^2

Approximately 60% of it is covered by vegetation (mainly forest and scrub). However, this landscape is highly fragmented. Although there are some very mountainous areas (Pyrenees, 1500-3000 m) with a cold winter climate, most of the area has a typical Mediterranean climate with mild winters and long summer drought that often generates forest fires.

Catalonia is divided geographically into 4 provinces, Barcelona, Girona, Lleida and Tarragona.

FIGURE 9. Provinces of Catalonia Source: http://www4.gvsu.edu/wrightd/SPA%20Cul%20Civ%20II/Cataluna.htm

2.2. Climate and geography

Generally, the climate in Catalonia is mediterranean, with plenty of sun. It is mild in winter and hot in summer. The region's morphological diversity determines the variations in its climate. In the Pyrenees and nearby areas, the climate is typical of mountainous regions, with minimum temperatures below 0ºC, annual rainfall above 1,000 mm and heavy snowfall in winter. Coastal areas have mild, temperate weather, with increasing temperatures and decreasing levels of rainfall the further south one travels. Inland, the climate is typical of continental mediterranean regions, with cold winters and very hot summers.

FIGURE 10. Barceloneta beach, Barcelona, hotel VELA in the left hand, Hotel ARS and MAFRE Tower in the right side. Source: http://www.solomoda.com/wp-content/uploads/2010/12/W-Barcelona-general-3.jpg

Catalan geography is divided into: the Pyrenees, the Central Depression, the Ebre Depression, the Catalan Mediterranean system, the coastal plains and the Cordillera Transversal. The impressive mountain range of the Pyrenees, with its east- and west-facing slopes, stretches from the Atlantic to the Mediterranean and separates the Iberian Peninsula from the rest of Europe.

FIGURE 11. Vall d'Aran, Central Catalan Pyrenees. Source: http://alfilodeloimpresentable.blogspot.com/2009/07/30-05-2009-montardo-2833-mts-vall-daran.html

In Catalonia the southeastern slopes of the range form a long strip that runs 230 km from the Val d'Aran to the sea. The axial Pyrenees are predominantly made up of granite and dark slatey areas and have steep sides and high peaks (the Estats peak is 3,143 m high, Comaloformo is 3,033 m and Puigmal is 2,193 m). There are also lower areas such as "La Cerdanya", with its very beautiful, diverse landscape marked by glacial cirques with tarns and pools, water courses that have cut out deep valleys, meadows and forest pine, fir trees and birch. The steep pre-Pyrenean folds of Montsec and Pedraforca largely consist of limestone. Protected areas include Aigüestortes and the Estany de Sant Maurici National Park, El Cadí-Moixeró Natural Park, the Natural Park of the Volcanic Region of "La Garrotxa", and the Cap de Creus Natural Park.

The Catalan Mediterranean system consists of three areas that run parallel to the coast: the Serralada Litoral, a range of mountains that stretches from the Garraf massif to the Begur massif; the Serralada Prelitoral, which stretches from Les Guilleries to Els Ports, with major massifs such as El Montseny, Montserrat and El Montsant; and between them the depression Prelitoral, which holds the most densely-populated regions of El Gironès, La Selva, El Vallès, El Penedès and El Camp de Tarragona. The natural parks in this area include the Garraf, El Montseny, Montserrat, Sant Llorenç del Munt and El Montnegre-Corredor parks.

The Central Depression, at the eastern end of the Ebre Depression, consists of a series of basins formed by erosion (the Plana de Vic, the Pla de Bages, the Conca de Barberà), high plateaus (La Segarra and El Lluçanés) and the alluvial plains (El Segrià and L'Urgell), which are largely used for growing crops. Other smaller distinctive areas include the coastal plains of l'Empordà and the Delta de l'Ebre, and the Serralada Transversal (Puigsacalm) mountain range. The natural parks of the Aiguamolls of L'Empordà and the Ebre Delta are on the coast and are important havens for migratory birds.

The sheer coastline consists of 580 km of steep cliffs interspersed with hidden or sandy coves, depending on the proximity of the mountains. The stretches of coastline are known to tourists as, from north to south, the Costa Brava, the Costa del Maresme, the Costa del Garraf and the Costa Daurada.

2.3. Environmental factors

Catalonia has the potential to produce 73499.4 thousand tonnes/year (Forest ecological inventory of Catalonia, CREAF updated annually). More than 35% of Catalan territory is forest. Some recent studies (acording to Abertis Foundation 2009) found that only in the Montseny and Montnegre-Corredor there is an annual equivalent of over 140,000 tons of oil.

The country's topography with steep slopes does not provide the easy mobilization of forest biomass. The slopes are more than 60% and because of that, it is difficult and expensive to do the forestry exploitation.

2.4. Economic factors

Forestry as an economic sector does not provide more than 4.28% of PIB in Catalonia, if we note that two thirds of Catalonia are defined as forest land, we have a clear idea of the low productivity of this sector. Since 2007 there is available a decree, in the Spanish State, that promotes renewable energy. This decree establishes the economic and financial balance between costs and benefits of using biomass as a renewable source of energy.

Other European countries, like Germany, have a law to promote the use of renewable energies since 2004. Nowadays, in Germany, they have 160 installations with a total power of 980 MWel. (information acording to the CTFC).

2.4.1. Summary of the economic situation

The economic situation can be defined according to the following list:

• POPULATION: The migration from abroad has been the main cause of population growth in Catalonia.

• REAL GROWTH: Catalan economic growth has been slightly lower than the national in the last decade.

• PRODUCTIVE STRUCTURE: The industrial sector strongly implemented in the Community, although in recent years there has been a decline.

• JOB MARKET: The unemployment rate has remained in Catalonia consistently lower than the Spanish rate in the last ten years, and experienced a significant increase in 2008 as the national average.

• PRICES AND WAGES: In the last ten years prices have risen more in Catalonia than in the whole country while wages have become slightly lower.

• EXTERNAL SECTOR: Catalonia is the community with a greater degree of openness abroad.

• INNOVATION AND NEW TECHNOLOGIES: The effort in R & D remains above the national average, with increasing tendency.

• INDUSTRIAL BUSINESS: The density of firms in Catalonia remains higher than the national average.

• CONVERGENCE: The slower economic growth and higher population growth is affecting to the GDP per capita.

• PUBLIC SECTOR: Indebtedness above the average of the Autonomous Communities, but has experienced a slight decline in the recent years.

*(*Source: ICO. Official Credit Institute, Spanish Ministry of Economy and Finance.)*

2.5. Status of renewable energies in Catalonia

Catalonia is, in fact, one of the most progressive territories in Europe considering renewable energy. The water systems in all new residential buildings since 2006, for example, must be heated by solar panels. In the last three years, the Catalan government has given more than 15 million euros, in grants to homeowners to help pay for their installations.

Catalonia has also declared a goal of procuring at least 11 percent of all energy used in the region from renewable sources by 2015. That plan specifies the amount of energy to come from various sources, like wind, solar, geothermal and biomass.

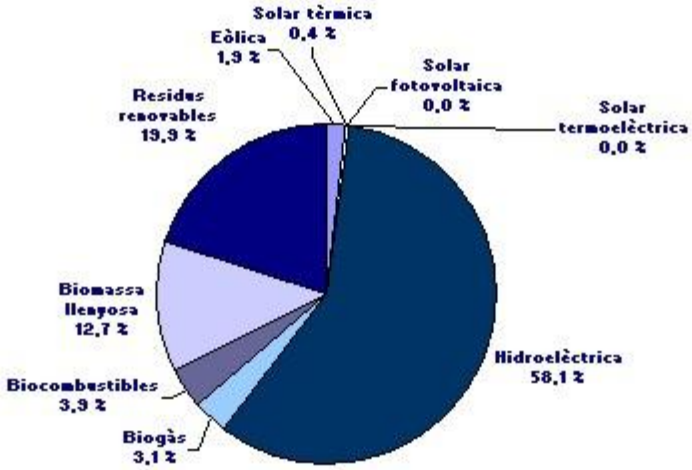


FIGURE 12. Renewable energies situation, 2007. Source: ICAEN.

The status of energy management in Catalonia is similar to the rest of the state, with certain specifications. Although the first Spanish wind farm was installed in Catalonia 25 years ago, most of autonomic comunities surpass us in the generation of energy from renewable energy sources (EERR).

FIGURE 13. Renewable energies. Source: ChileCarbon.

Currently, the contribution of **renewable energy** in primary energy balance in Catalonia is reduced. In 2007 the total consumption of renewable energies in terms of primary energy was **742.5 ktoe**, representing **2.8%** of the total primary energy consumption in Catalonia this year and the 3.1% if non-energy uses are considered.

If we analyze each of the renewable sources present in the country may be noted that:

- The **hydropower** is the main renewable source present in Catalonia. On December 31 of 2007 gross electric power from hydropower was 2360.6 MW, representing a gross production of 3,576.4 GWh of electricity, equivalent to 78.4% compared to the production of electricity from renewable energy.

- The consumption of **biomass** represented 236 ktoe in terms of primary energy in 2007, equivalent to 31.8% of total consumption of renewable energy. Of these:

  - ✓ **Biogas** represents a 40.8 ktoe in terms of consumption of primary energy.
  - ✓ **Biofuels** represent a consumption of 101.5 ktoe in terms of primary energy.
  - ✓ The consumption of **wood biomass** represents a 93.7 ktoe in terms of primary energy.

- The consumption of **renewable waste** represented 134.3 ktoe in terms of primary energy in 2007, equivalent to 18.1% of total consumption of renewable energy.

- The gross production of electricity from **wind** origin in Catalonia in 2007 was 498.0 GWh, equivalent to 1.1% of total gross production of electricity and 10.9% of production from renewable sources.

- The gross production of **photovoltaic** power source in Catalonia in 2007 was 29.7 GWh. That same year, the gross electric power installed on 31st of December was 34.4 MW.

TABLE 2. Status of renewable energy, 2007. Source: ICAEN

Renewable source	Description	production (ktoe)	%
Wind	342.4 MW installed	42.8	5.8
Solar Photovoltaic	34.4 MW installed	2.6	0.3
Solar Thermal Power	0.0 MW installed	0	0
Solar thermal	280000 m2	19.3	2.6
Hydroelectric	2,360.6 MW installed	307.5	41.4
Biogas	43.1 MW for electricity production + thermal uses	40.8	5.5
Biofuels	81 ktn of producing biodiesel	101.5	13.7
Wood Biomass	Uses direct thermal + 0.5 M W for electricity production	93.7	12.6
Waste renewable	44.4 MW installed in MSW	134.3	18.1

2.6. Status of biomass in Catalonia

The energy use of biomass waste has increased over the recent years in Spain and Catalonia. The main reason for this increase is the need to meet energy goals at the regional and state level specified in the *Pla de l'Energia de Catalunya 2006-2015* for Catalonia, and the *Plan Nacional de Energías Renovables 2005-2010* for Spain. These goals are directly related to the limitations on the emission of greenhouse gases (GHG), signed in the Kyoto Protocol.

Catalonia is developing the Energy Plan for Catalonia, Plan 2006-2015, which includes renewable energy issues. The utilization of renewable energy sources is a priority for the Goverment of Catalonia. The estimated contribution of wood biomass primary energy consumption in Catalonia for the year 2015 is illustrated in the following tables, in wich two scenarios are considered: the baseline scenario and the renewable energy efficiency (IER) scenario.

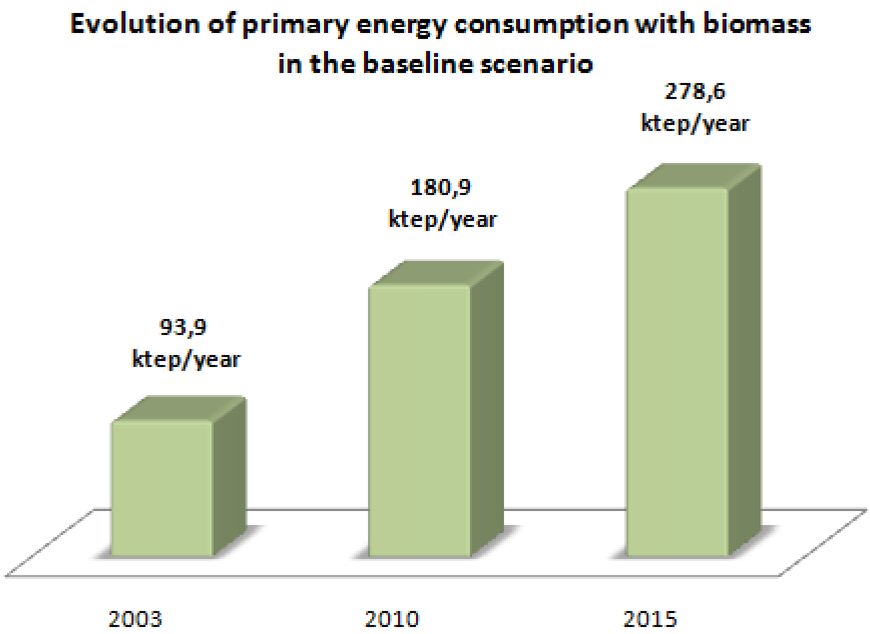


FIGURE 14. Evolution of primary energy consumption with biomass in the baseline scenario in Catalonia.

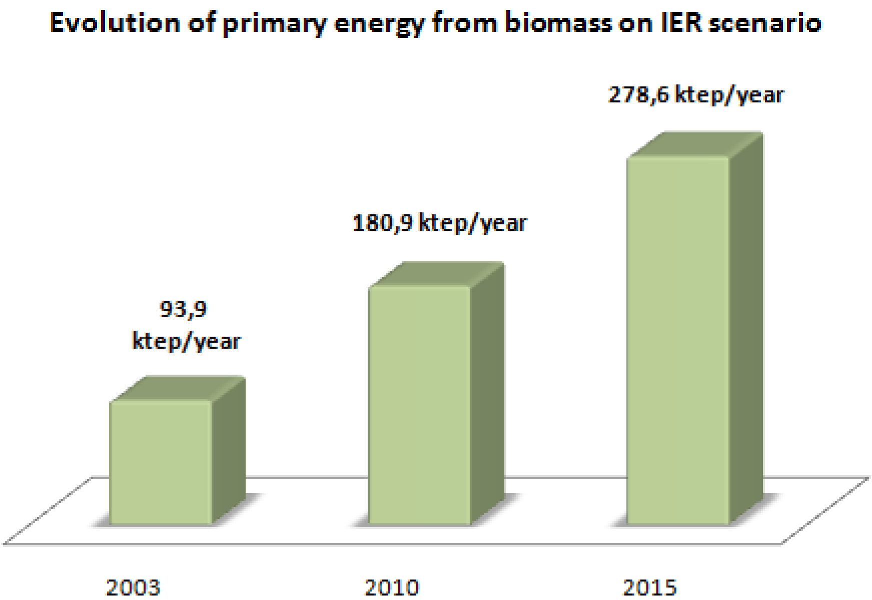


FIGURE 15. Evolution of primary energy from biomass on IER stage in Catalonia.

This Plan is proposing the thermal use promoting forest biomass facilities in areas of high thermal demand, mainly industrial and tertiary sector. In addition, the Plan is also providing grants to the power plants operating with this renewable resource. The objective for 2015 is to provide 278.6 ktoe on the stage IER from the woody biomass (agricultural and forestry). The most part of the consumption aims to thermal facilities. The total power amounts to 63.7 MW.

2.7. Future of energy in Catalonia

The Energy Plan for Catalonia 2006-2015 proposes objectives in the field of renewable energies very ambitious because it will multiply by four the consumption of renewable energy, increasing the 740 ktoe of renewable sources in 2003 to 2949 ktoe in 2015. It is expected that the percentage share of renewables in primary energy balance will increase from 3.6% in 2003 to 11% in 2015 (acording to ICAEN).

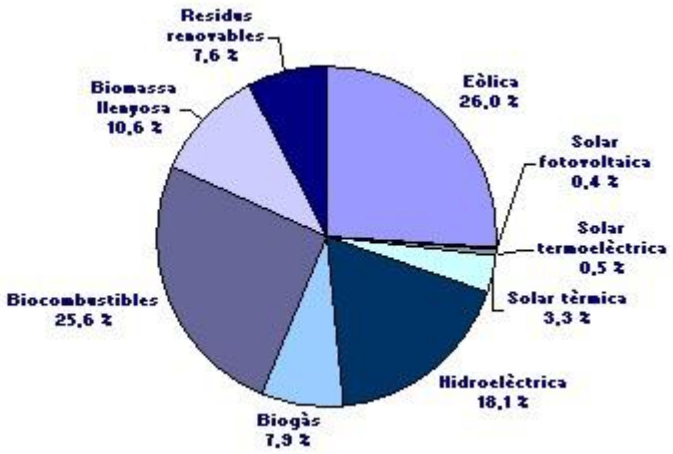


FIGURE 16. The future of renewable energy in Catalonia. Source: ICAEN.

Biofuels represent 25.6% of renewable energy consumption in Catalonia thanks mainly to the importance of biodiesel which is expected to replace 15% of the consumption of automotive diesel.

The whole **biomass and biogas** 512.1 ktoe will bring some energy balance by 2015, representing 17.4% of total renewable energy.

Wind power will also have a very important role, the installation of 3,500 MW. It is expected that 25.7% of the consumption of renewable energy source is from wind.

Hydropower, which has traditionally been the most important in Catalonia, has a very limited growth potential. However, this energy source even contributes to a 17.9% renewable energy consumption in Catalonia.

Solar energy also has some very ambitious goals. Regarding photovoltaic energy, with 100 MW, the growth is 44% over the current situation. For solar thermal energy, the goal is to reach 1.25 million m^2 for the collectors. It also proposes the construction of the first solar thermal plant in Catalonia.

TABLE 3. The future of renewable energy in Catalonia, Description and production. Source: ICAEN

Renewable source	Description	Production (ktoe)	%
Wind	3300 MW	681194	26
Solar photovoltaic	100 MW	10213	0.4
Solar Thermal Power	50 MW installed	12040	0.5
Solar thermal	1,250,000 m2	86050	3.3
Hydroelectric	2,423.8 MW (48.1 MW in new RE)	472,439	18.1
Biogas	121.5 MW allocated to the exploitation of biogas electricity + THERMAL USES	205570	7.9
Biofuels	15% of the demand for biodiesel oils + production of bioethanol (ETBE) 6% of all petrol	669144	25.6
Wood Biomass	Direct thermal applications that increase over 2003 in 50 ktoe + 51.4 MW for electricity	278620	10.6
Waste renewable	45.2 MW MSW + 52 ktoe of sewage sludge for thermal uses	198781	7.6
* Value calculated excluding non-energy uses of oil			

Much of the total renewable energy consumption in Catalonia will be from wind, namely 26% of total renewables. Hydroelectric energy has a very limited growth potential. Currently the energy use of the rivers in Catalonia has practically reached saturation. Catalonia has pioneered in collaboration between private companies and universities, mainly through the development of the renewable energy sector in the country. There is a need to know if the current economic crisis will affect the future of renewable energy in Catalonia.

2.8. Companies and organizations

The government of Catalonia has a number of agencies involved in the development and application of energies. It is very important to have their performance within the state, and thanks to their collaboration, communication is achieved between all companies, organizations or associations, both public and private, operating in that field. Their common mission is securing their interests in the use of renewable energies. The mission of some of these organisms are explained in the next three points.

2.8.1. ICAEN

Generalitat de Catalunya
Institut Català
d'Energia

The Catalan Institute of Energy aims at promoting and implementing initiatives and programs of action for research, study and support the actions of knowledge development and application of energy technologies, including renewables, improvingenergy conservation and energy efficiency, promoting the rational use of energy and, in general, the optimal management of energy resources in different economic sectors in Catalonia.

With the approval of the Energy Plan for Catalonia 2006-2015, 11 October 2005 and its subsequent revision adopted on 24 November 2009, the government set the strategic principles that should guide the performance of the Catalan public in the coming years, the road to a new awareness of energy.

Under these new criteria, the Catalan energy policy has to be developed around the following axes:

- **Improve** awareness and knowledge about the energy issue.
- **Promote** energy **conservation** and energy **efficiency**.
- **Promoting** renewable energy sources.
- **Developing** energy infrastructure to ensure supply.
- **Diversify** energy sources.
- **Supporting research**, development and technological innovation in the energy field.

Social awareness and technological progress are the factors that broadly define the path towards sustainable energy development.

The Catalan Institute of Energy wants to be the instigator of this process of transformation and change, which should be linked to different economic and social agents in the country in order to assure shared future challenges arising locally in the field of energy. The goal of sustainability can only be achieved together.

2.8.2. CFTC

The Forest Technology Centre of Catalonia (CTFC), based in Solsona (Lleida, Spain), began in 1996 in the form of a consortium jointly run by Solsonès County Council, the University of Lleida, Lleida Provincial Council, the Catalan Foundation for Research and Innovation, the Integrated Rural Development Centre of Catalonia and the Government of Catalonia. Its dynamic operation has been characterised by growth meaning that nowadays the institution has more than a hundred professionals on its staff, including scientists, technicians, students on work placements and administrative staff, and it enjoys the support of administrations, institutions and companies that help with its day-to-day work.

The CTFC's activity is not merely restricted to competitive research but also includes technology and knowledge transfer and training, which represents a considerable volume of its activity, making use of its results. Technology transfer in the form of agreements with the private sector and public administrations is complemented with the organisation of seminars for the general public and agents from the sector (managers, owners, experts, the administration, scientists, etc.) at national and international level, contributing to the transfer of this knowledge and the generation of debate. In the training sphere, the CTFC's activity embraces everything from basic training for workers to life-long learning and specialised education in the form of post-graduate studies and master's degrees.

This activity carried on by the CTFC fits into its institutional mission, which is to contribute to the modernisation and competitiveness of the forestry sector, rural development and the sustainable management of the environment through research, training and technology and knowledge transfer to society.

2.8.3. DMAH

The Department of Enviroment and housing has a role of intermediation under the map of Catalonia in sustainability research.

On one hand, it acts as an intermediary between the knowledge required forpolicy making and public management, and universities, research centers and companies. On the other hand, it channels the demands of social research to universities, research centers and technology transfer and business.

To be more specific:

The focus and prioritization of research into sustainability of the country to collect theseneeds in the framework of the research and innovation.

The support-through-direct funding to R & D carried out by universities and research centers, especially those ICRA, IC3, CREAF, the CTFC, the Creal, the 'ICF and ICS.

The facilitation of research are universities and research centers, all data collected on a regular basis and encouraging networking and professional knowledge.

The dissemination and communication of research results internationally should take place between state and Catalan society.

2.9. Biomass plants in Catalonia

Catalonia has 16 operating facilities with biomass energy production, mostly from thermal production. Most boilers installed consume less than one thousand tons per year of fuel and are used for residential heating. Only four facilities maintain higher biomass consumption. These are described below.

In Mora d'Ebre (Tarragona) is running the only gasification plant with electricity production from almond shells (500 kWe). The installation consumes 2,150 tons of biomass. With a similar consumption exists the central heating plant located in the town of Molins de Rei (Barcelona province), in development called "La Granja ". This is the biomass plant that aims this thesis.

The thermal plant of Sant Pere de Torello (Barcelona Province) consume 5,000 kg / year of biomass, in order to increase its heat production and consumption of biomass up to 45000 kg / year (still pending).

Finally, in Solsona (Lleida) stressed the heat production plant largest in Catalonia, with an annual consumption of wood processing waste of nearly 30,000 Mg.

Soon there may operate new power plants with biomass production that are currently in administrative proceedings. These include the power plant of La Senia (Tarragona), which provides an annual consumption of approximately 70,000 kg of waste wood and others. In La Garriga there is another plant with a consumption of 60,000 Kg per year of forest waste.

2.10. Status of biomass in Spain

The National Centre for biomass boilers registers more than 1,200 installations and 250 MW power.

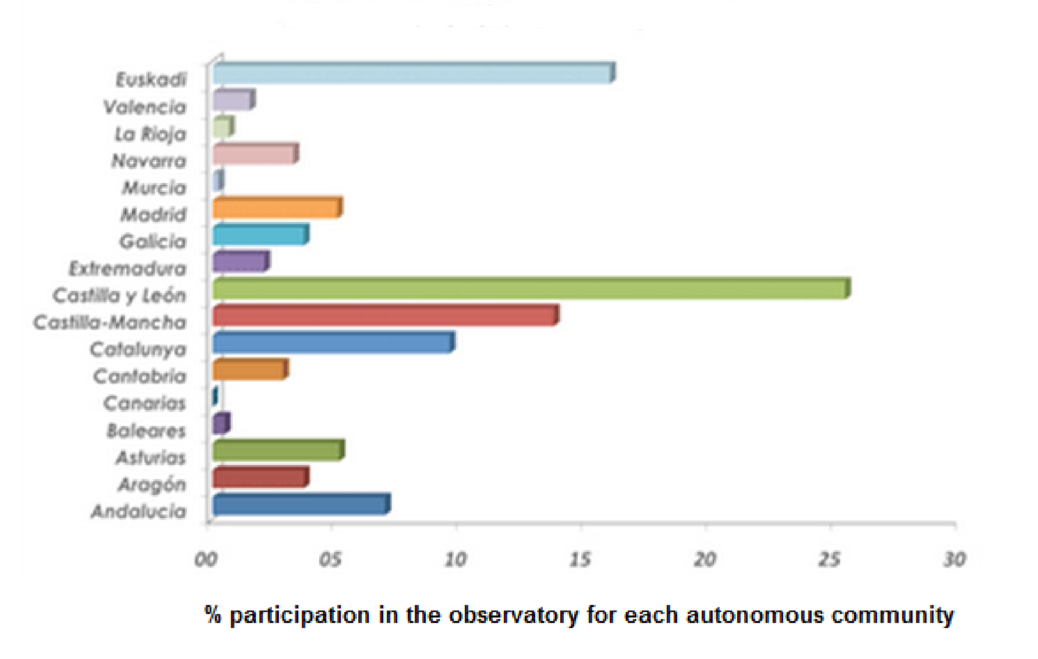


FIGURE 17. Autonomous community biomass boilers %.
Source: AVEBIOM SPAIN, 30th of April 2010.

The Spanish Association for Energy Recovery from Biomass (AVEBIOM) has released the first data from the National Observatory of biomass boilers. The data analyzes in detail the development of small and medium thermal facilities in residential, public and industrial use. Since its launch in December 2009, there have been more than 1,200 installations and 250 MW.

The Centre can know the size of the sector and its future trend in the number of companies and economic volume. It provides estimates of consumption of solid biofuels and their geographical distribution. Also, it allows to evaluate the reduction of energy costs and analyzes the competitiveness of enterprises and job creation, resulting from the change to biomass boilers reducing emissions of CO_2 and other greenhouse gases.

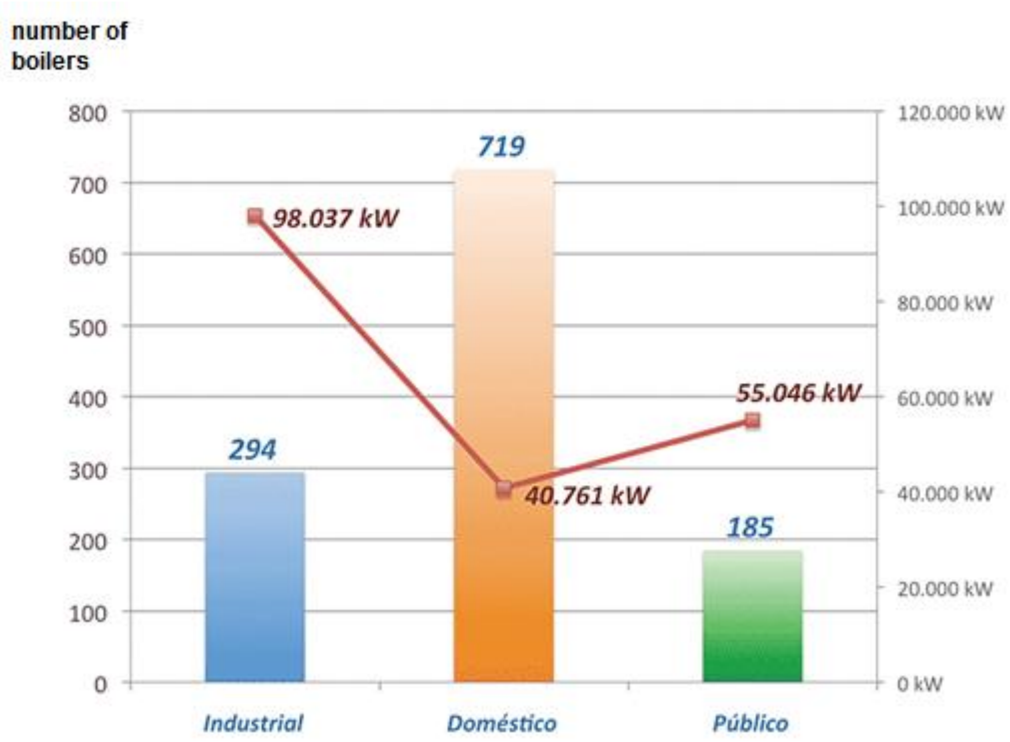


FIGURE 18. Industrial, Domestic and Public biomass power consumption. Source: AVEBIOM SPAIN, 30th of April 2010.

After analyzing in detail all these points, the Centre generates various reports to potential new users, government (to have a guidance tool for regional and national policies for the better development and implementation of biomass facilities) and corporate requiring updated and detailed information for making business decisions. The thermal use of biomass is very competitive with fossil fuels: fuel savings over 40% and even with the use of wood chips, can reach 80%. The mobilization of biomass for thermal use will depend on the number and power boilers installed.

CHAPTER 3: Heating and Cooling with Biomass

This chapter aims to explain the technical concepts in order to help in the better understanding of the system knowledge. The chapter, explains the terms of cogeneration and trigeneration, both with biomass as main source.

3.1. What is Cogeneration?

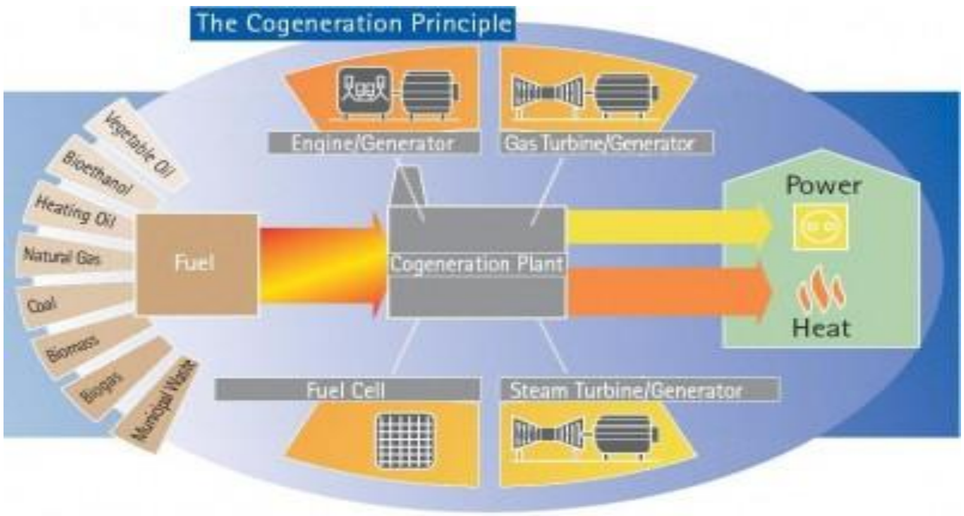


FIGURE 19. The Cogeneration Principle. Source: Eurostat (2009): Combined Heat and Power (CHP) in the EU, Turkey, and Norway – 2007 data.

Cogeneration (Combined Heat and Power or CHP) is the simultaneous production of electricity and heat, both of which are used. The central and most fundamental principle of cogeneration is that, in order to maximise the many benefits that arise from it, systems should be based on the heat demand of the application. This can be an individual building, an industrial factory or a town/city served by district heat/cooling. Through the utilisation of the heat, the efficiency of cogeneration plant can reach 90% or more. Cogeneration therefore offers energy savings ranging between 15-40% when compared with the supply of electricity and heat from conventional power stations and boilers.

Cogeneration optimises the energy supply to all types of consumers with the following **benefits** to both users and society at large:

- **Increased efficiency** of energy conversion and use. Cogeneration is the most effective and efficient form of power generation.

- **Lower emissions** to the environment, in particular of CO_2, the main greenhouse gas. Cogeneration is the single biggest solution to the Kyoto targets.

- **Large cost savings**, providing additional competitiveness for industrial and commercial users, and offering affordable heat for domestic users

- An opportunity to move towards more decentralised forms of electricity generation, where plant is designed to meet the needs of local consumers, providing high efficiency, avoiding transmission losses and increasing **flexibility in system** use. This will particularly be the case if natural gas is the energy carrier.

- Improved local and general **security of supply** – local generation, through cogeneration, can reduce the risk that consumers are left without supplies of electricity and/or heating. In addition, the reduced fuel need which cogeneration provides reduces the import dependency – a key challenge for Europe’s energy future

- An opportunity to increase the **diversity of generation plant**, and provide competition in generation. Cogeneration provides one of the most important vehicles for promoting liberalisation in energy markets.

- **Increased employment**, a number of studies have now concluded that the development of CHP systems is a generator of jobs.

3.1.1. The role of cogeneration in total electricity generation in Europe

The European Union currently generates 11% of its electricity using cogeneration. However, there is large difference between Member States with variations of the share of cogeneration between 0% and 42,8%. According to the official Eurostat figures from 2007, there is no cogeneration in Malta, very little in Cyprus (0,3%) and Greece (1,6%). Denmark has the greatest share of cogeneration in total electricity generation (42,8%) followed by Latvia (40,9%). Significant potential exists in new Member States particularly for refurbishment of district heating schemes and their upgrade to include modern cogeneration where previously only heat was distributed. This is universally the case where a large district heating infrastructure already exists. For more information on the potential of cogeneration in Europe, visit www.code-project.eu

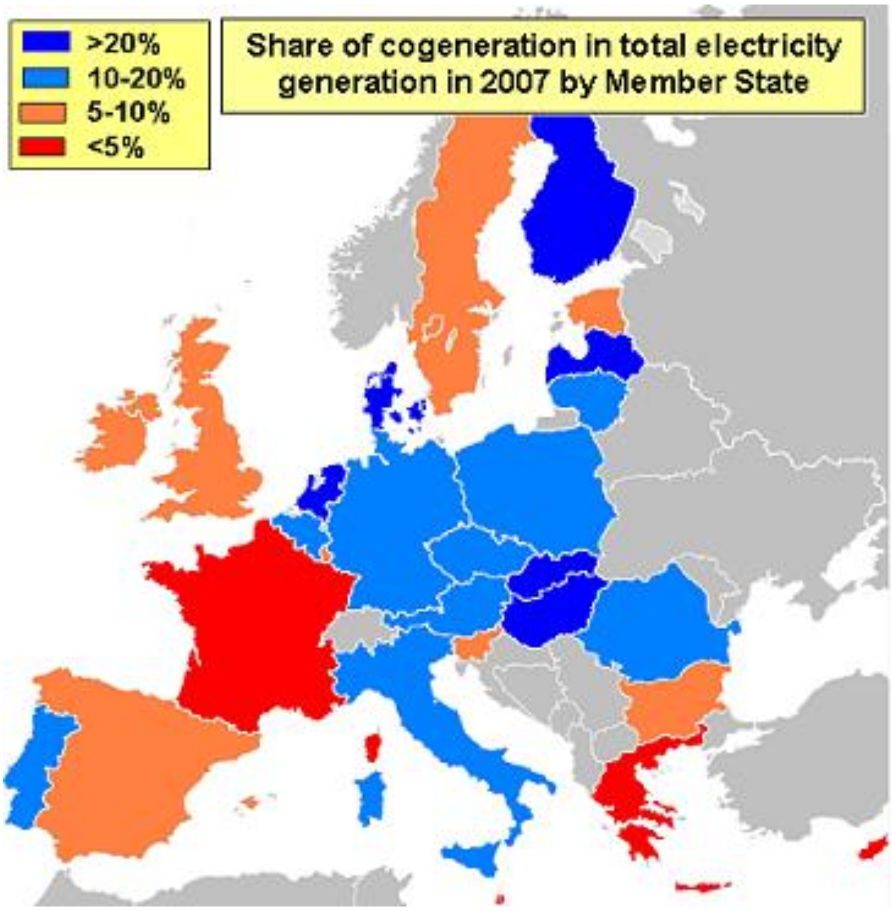


FIGURE 20. Share of cogeneration in total electricity generation, 2007. Source: Eurostat (2009): Combined Heat and Power (CHP) in the EU, Turkey, and Norway – 2007 data.

3.1.2. Common CHP plant types

In this point is shown a summary of the different types of CHP plants:

- **Gas turbine** CHP plants using the waste heat in the flue gas of gas turbines. The gaseous fuel used is typically natural gas.
- **Gas engine** CHP plants (in the US "gaseous fuelled") use a reciprocating gas engine which is generally more competitive than a gas turbine up to about 5 MW. The gaseous fuel used is normally natural gas. These plants are generally manufactured as fully packaged units that can be installed within a plant room or external plant compound with simple connections to the site's gas supply and electrical distribution and heating systems.
- **Biofuel engine** CHP plants use an adapted reciprocating gas engine or diesel engine, depending upon which biofuel is being used, and are otherwise very similar in design to a Gas engine CHP plant. The advantage of using a biofuel is one of reduced hydrocarbon fuel consumption and thus reduced carbon emissions.

These plants are generally manufactured as fully packaged units that can be installed within a plant room or external plant compound with simple connections to the site's electrical distribution and heating

systems. Another variant is the wood gasifier CHP plant whereby a wood pellet or wood chip biofuel is gasified in a zero oxygen high temperature environment; the resulting gas is then used to power the gas engine.

- **Combined cycle** power plants adapted for CHP
- **Steam turbine** CHP plants that use the heating system as the steam condenser for the steam turbine.
- **Molten-carbonate fuel cells** have a hot exhaust, very suitable for heating.
- **Nuclear Power** plants can be fitted with steam drains after the high, mid, and/or low pressure turbines to provide heat to a heat system. With a heat system temperature of 95°C it is possible to extract about 10 MW heat for every MW electricity lost. With a temperature of 130°C the gain is slightly smaller, about 7 MW for every MWe lost.

Smaller cogeneration units may use a reciprocating engine or Stirling engine. The heat is removed from the exhaust and the radiator. These systems are popular in small sizes because small gas and diesel engines are less expensive than small gas- or oil-fired steam-electric plants.

Some cogeneration plants are fired by **biomass**, or industrial and municipal waste.

TABLE 4. Cogeneration Technology Characteristics. Source: ENERGY TECHNOLOGY FACT, UNEP.

Technology	Fuel	Size (MW_e)	Electrical efficiency	Overall efficiency	Average capital cost in $/kW$_e$	Average Maintenance in $/kWh
Steam Turbine	Any	0.5-500	7-20%	60-80%	900-1800	0.0027
Gas Turbine	Gaseous and liquid fuels	0.25-50+	25–42%	65–87%	400-850	0.004-0.009
Combined cycle	Gaseous and liquid fuels	3-300+	35–55%	73-90%	400-850	0.004-0.009
Diesel and Otto engines	Gaseous and liquid fuels	0.003-20	25–45%	65-92%	300-1450	0.007-0.014
Micro turbines	Gaseous and liquid fuels		15-30%	60-85%	600-850	<0.006-0.01
Fuel cells	Gaseous and liquid fuels	0.003-3+	App 37-50%	App. 85-90%	?	?
Stirling engines	Gaseous and liquid fuels	0.003-1.5	App. 40%	65-85%	?	?

3.2. What is Trigeneration?

The term trigeneration describes an energy system with combine heat, power and cold generation (CHCP). The system consists basically of a CHP (combined heat and power) module generating electricity and heat, and a thermally driven chiller, generating cooling. The chiller is driven with the heat delivered by the CHP. Depending on the demand, the generated heat is either used for heating or cooling purposes or both.

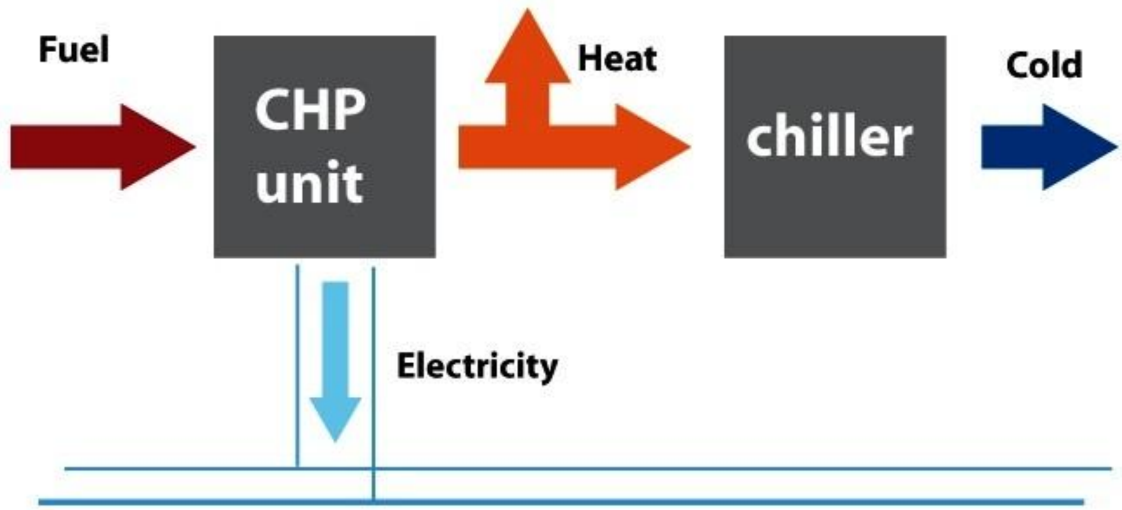


FIGURE 21. Trigeneration main parts.
Source: PolyGENERATION in EUROPE.

Trigeneration systems are used wherever there is demand for heat, cooling and power. This means that the application area is very wide, ranging from small residential to large commercial (office, hotels, schools, sports, entertainment centres, hospitals, airports, etc.) buildings and from small trade to industry facilities. In buildings, the CHCP system produces heat for domestic hot water, space heating or desiccant dehumidification and cold for space cooling or air-conditioning. While in trade and industrial business (e.g. in food industry), heat and cooling is additionally needed for production processes (heating, steam generation, drying, cooling, freezing, etc).

Trigeneration systems can operate in a range of configurations. The most common system is decentralized trigeneration. In this case heat and cooling are generated and consumed onsite, while power is either consumed onsite or fed into network. Another option is to generate heat and power in centralized CHPs and distribute it to end-users, where thermally driven chillers generate cold decentralized. Furthermore, concepts of centralized CHCP systems exist, where heat, cold and power are generated centrally and then distributed to end-users.

Biomass cogeneration is widely used for district heating applications in central and northern Europe. Biomass **trigeneration** on the other hand, constitutes an innovative renewable energy application.

In this work, an approved United Nations Framework Convention on Climate Change baseline methodology has been extended to allow the examination of biomass trigeneration applications.

The results suggest that trigeneration may lead to significant emissions reduction compared to using fossil fuels or even biomass cogeneration and electricity generation.

TABLE 5. Comparison of the trigeneration scenario and the baseline scenario (as is). Source: Biomass District Energy Trigeneration Systems: Emissions Reduction and Financial Impact. A. Rentizelas & A. Tolis & I. Tatsiopoulos, 2008.

	Baseline scenario (as is)	Trigeneration scenario
Electricity	National grid's current generating mix	Generated by biomass CHP—energy fed to the national grid
Heating	Domestic diesel oil boilers	Generated by biomass CHP and biomass boiler for peak load—energy distributed via district energy network
Cooling	Domestic electric heat pumps	Conversion of heating to cooling via absorption chillers—energy distributed via district energy network
Alternative use for biomass	Dumping, decay, or burned in uncontrolled manner	–

3.3. District heating

In this point are explained the main points about the district heating system.

The heat is normally produced from burning biomass, thermal water or solar panels. Hot water is distributed through a network of highly insulated pipes to each point of consumption (housing, hospitals,...).

The usual method is to place a circuit flow and return pipes (double tube). Depending on the size of the communities to be heated it is necessary to allow the installation of intermediate storage tanks of hot water to cope with peak demand. Normally, the grid is buried in the ground about 60 cm deep, but overhead networks can be run as well.

In connection to each house a heat exchanger is placed, so that water does not enter from the primary circuit in each house, there are heat transfers only. In each heat exchanger is also posted a counter to control the consumption of each neighbor. Thus costs are individualized and every consumer is aware of their spending and they can put into practice measures to reduce energy consumption. With using of a biomass boiler, to produce hot water and heating, we are avoiding to have a gas tank or diesel tank close to home and removing all gas pipes inside and outside home.

Thanks to this centralized system, the space which would occupied by the boiler for each house is free, although it is necessary to place a small closet with hydraulics systems.

3.3.1. Advantages

The advantages of this system are:

- It is more economical and environmental than any other system based on conventional energies. (Working Document nº 24 of CONAMA 10: Current Status and Future Trends Biomass www.conama10.es)

- Better performance and less pollution than individual heating systems.

- Supplies energy directly to the user, avoiding the need for handling and storing fuels, with the problems of dirt and danger that implied.

- Do not generate odors

- System and installation is quieter than conventional ones.

- Avoids the supervision and maintenance of the boiler of each resident, improving efficiency.

- Does not affect the interior installation in each home so that it can be used without any changes.

- The boiler in DH, because of their higher power, are equipped with an advanced system for cleaning the smoke, which is much better than in the individual boilers.

3.3.2. Disadvantages

The disadvantages of the system are:

- The installation requires more space than with conventional energies.

- It needs higher fuel storage volume for the same power production than with fossil fuels.

- Earth moving is required for opening and closing of ditches.

3.4. District Heating in Spain, some examples

- Cuellar, Segovia: 239 houses, a sports hall, a swimming pool, school and a cultural center.

The characteristics of this plant are:

Two water tube boilers: one of 4,500 Mcal / h with two overlapping grates capable of supplying hot water for heating and hot water in winter and another of 600 Mcal / h, witha grate, for the ACS in the summer.

The hot water pump is driven with a volume of 250 m^3 through a double pre-insulated piping. The heat arrives to every internal circuitry of each home through a heat exchanger, and returning cold water to the power station to start the cycle again.

Additional equipment to the facility is a fuel storage silo with a capacity of 30 tons of biomass.

FIGURE 22. Biomass plant located in Cuellar, Segovia.
Source: http://habitat.aq.upm.es/bpes/onu00/bp347.html

- Oviedo: 500 houses and a gym.

FIGURE 23. Oviedo biomass plant. Source: http://www.iciforestal.com.uy

Renewable energy generation from a biomass plant in Ence Navia was increased by 30.3% in 2010 over the previous year. The plant produced 470,878 megawatt hours (MWh) of energy, equivalent to consumption of more than 134,500 homes, for which 343,167 tons of biomass were consumed.

The company stressed that the management of the external biomass can generate greater number of forestry jobs in the rural area, providing "job security to the inhabitants of these areas and help to clean the mountain for better conservation and sustainable use."

The activity of the power plant in Ence Navia generates about 740 jobs. In addition, Ence provides income of around 28 million euros per year to landowners, forestry, loggers and transporters. The total contribution of the forestry Ence is 7.1% of GDP in the primary sector of Asturias.

Energy production from biomass also has clear environmental benefits, since the work on the mountain can reduce the fire risk by 70% due to the periodic forest cleaning, collection of agricultural residues and pruning of fruit trees.(Europa press, economy news, 2010)

- Molins de Rei, Barcelona: 695 users, district heating.

The plant of Molins the Rei is the model for the main objective of this thesis. This project is fully explained in the next CHAPTER 4 of the thesis.

3.5. European Heat Market

There is a study of the target area for this heat market assessment in the 32 European countries (according to the International Energy Agency IEA, Energy balances).

These countries are:

• The current EU25, divided into two sub-groups: the former EU15 before May 2004 and NMS10, the ten new member states from the enlargement in May 2004.

• The four accession countries in the ACC4 group (Bulgaria, Romania, Turkey, and Croatia)

• The EFTA countries in the EFTA3 group (Iceland, Norway and Switzerland)

These four sub-groups, defined according to Table 6, will be used throughout the report.

TABLE 6. The 32 countries examined divided into to four different groups.

EU15	NMS10	ACC4	EFTA3
Austria	Cyprus	Bulgaria	Iceland
Belgium	Czech Republic	Croatia	Norway
Denmark	Estonia	Romania	Switzerland
Finland	Hungary	Turkey	
France	Latvia		
Germany	Lithuania		
Greece	Malta		
Ireland	Poland		
Italy	Slovak Republic		
Luxembourg	Slovenia		
Netherlands			
Portugal			
Spain			
Sweden			
United Kingdom			

- EU25 + ACC4 + EFTA3 = 32 countries
- Facts about heat demands
- Focus on the industrial, residential, and service sectors

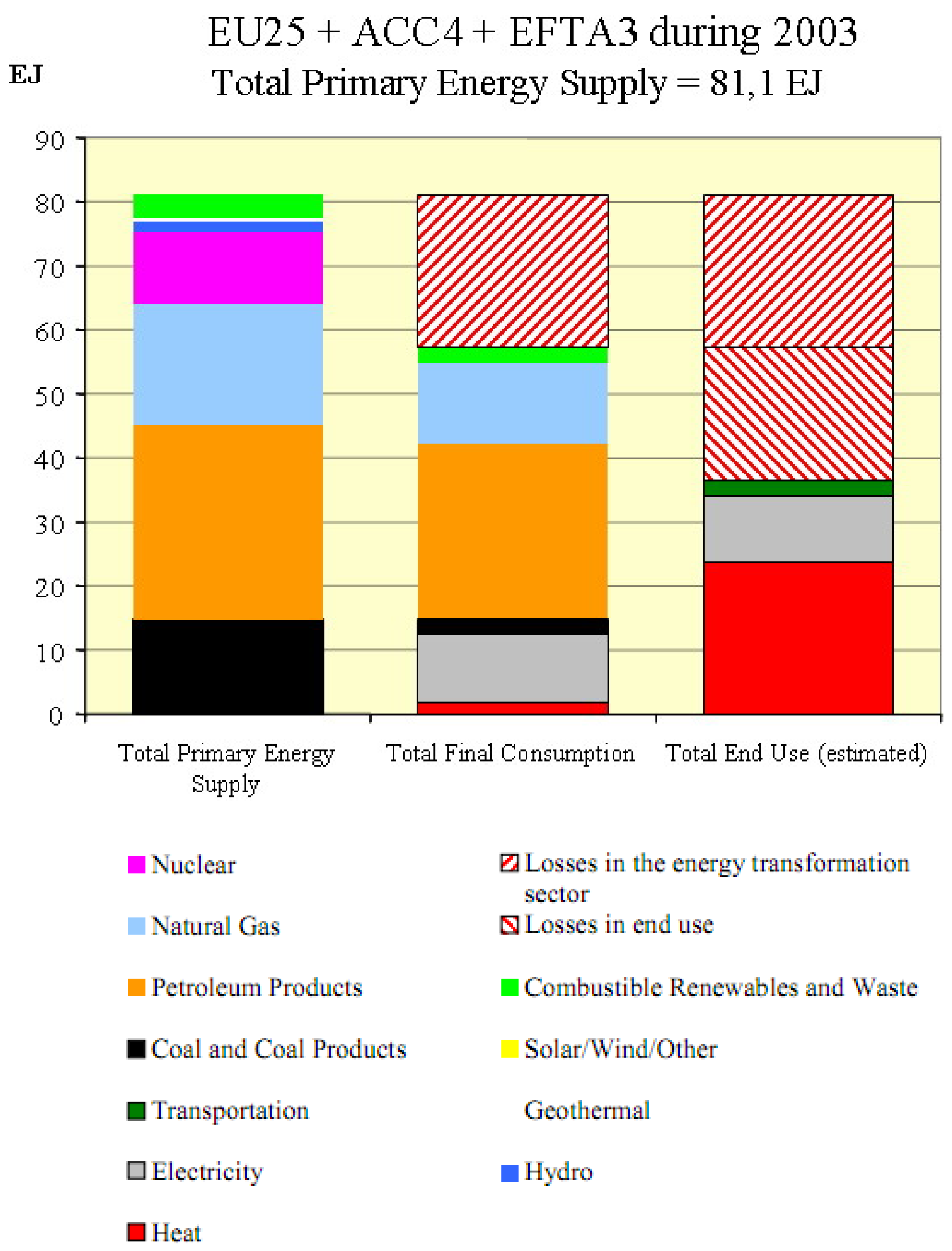


FIGURE 24. Energy supply. Source: European Energy Forum, 2005.

The figure shows the supply, the consumption and the estimated total end use of heating. Petroleum products are the most supplied and heat is the main use of the consumption.

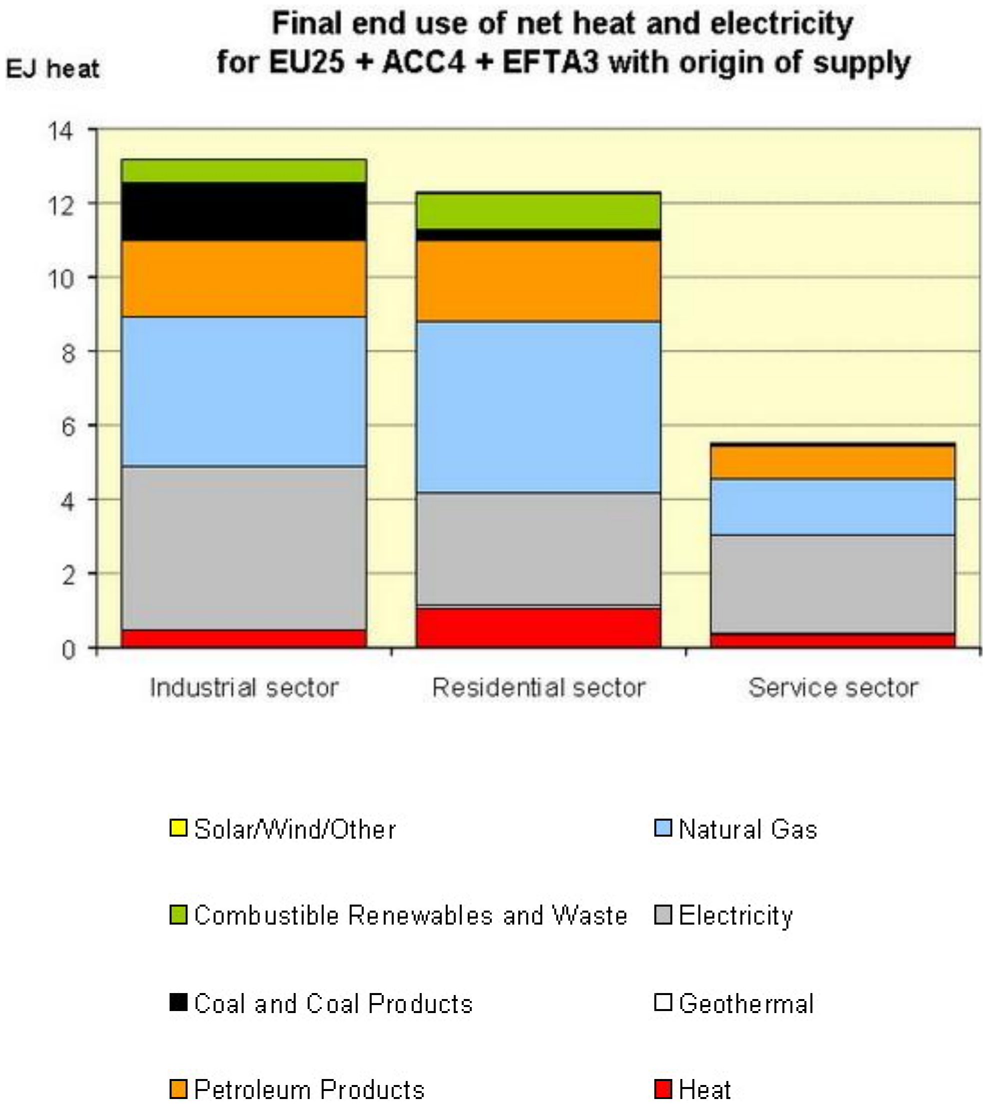


FIGURE 25. Final end use of net heat and electricity (origin of suply). EU25+ACC4+EFTA3.

This is the distribution of the heat uses divided into the three biggest consumption sectors, industrial, residential and service. The industrial sector and the residential sector are the main users of net heat and electricity.

As we can see in the figure, heat use is dominated by the supply of natural gas and electricity.

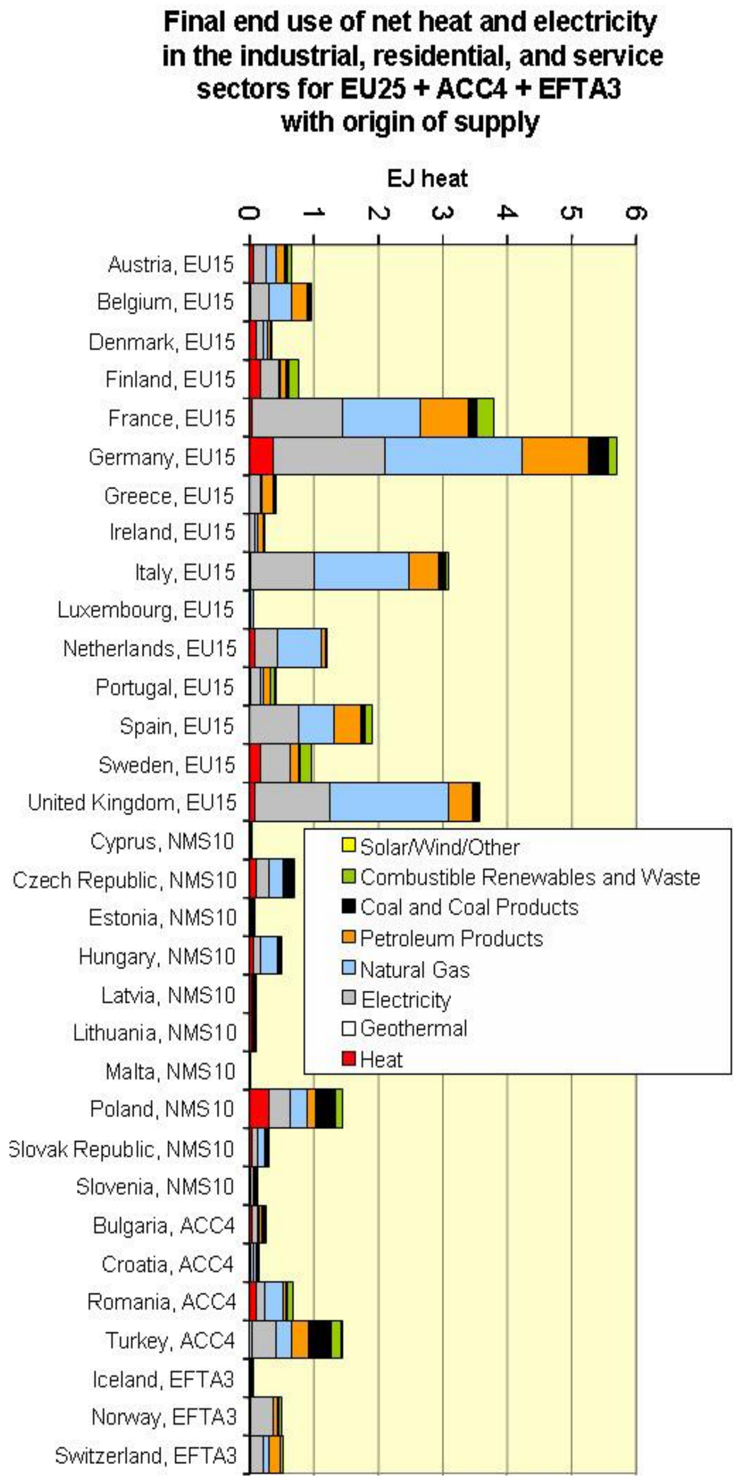


FIGURE 26. Final end use of net heat and electricity per country (origin of suply). EU25+ACC4+EFTA3.

3.5.1. Conclusions

The conclusions are summarized in the following summary:

- Heat dominates the European energy demand
- Heat use is dominated by the supply of natural gas and electricity
- The same heat demand in Western, Central, Eastern, and Northern Europe
- International heat statistics can be improved
- No major physical constraints for more district heat in Europe. Expansion is possible
- The mision of district heating is to:
  - decrease all carbon dioxide emissions with X %
  - increase security of supply with X %
  - increase the overall energy efficiency with X %

3.6. District Cooling as a Future Alternative

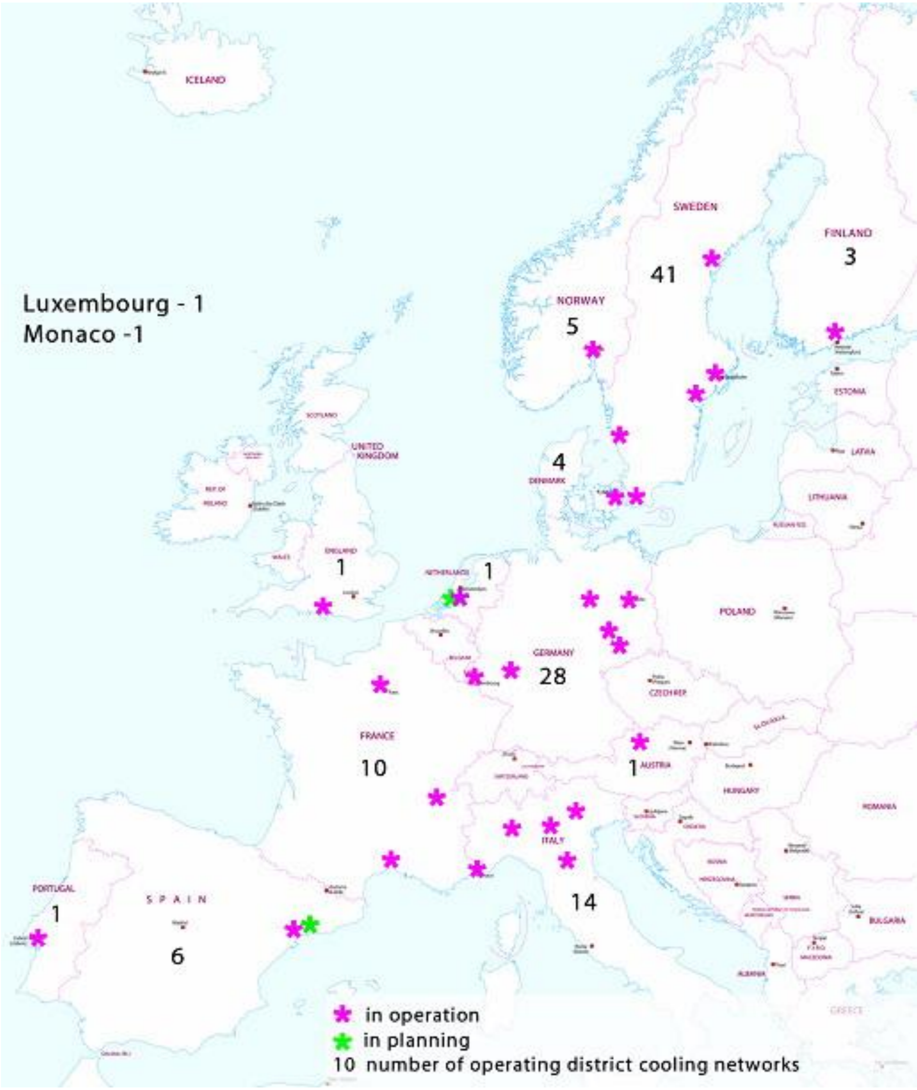


FIGURE 27. Indicative mapping of district cooling networks and on-site cooling installations (5 biggest indicated per country).
Source: ECOHEATCOOL.

CHAPTER 4: The plant of Molins de Rei

4.1. Introduction of the plant

The plant was designed and promoted in 1997 by the city council of Molins de Rei, EMSHTR(Municipal Authority Water Services and Waste Management), ICAEN (Catalan Institute of Energy) and the Company Efiensa. This group created Molins Energy Company, Ltd., to build and maintain a system of heat generation from biomass to distribute hot water to 695 new homes in a residential complex called ”La Granja” through a district heating network.

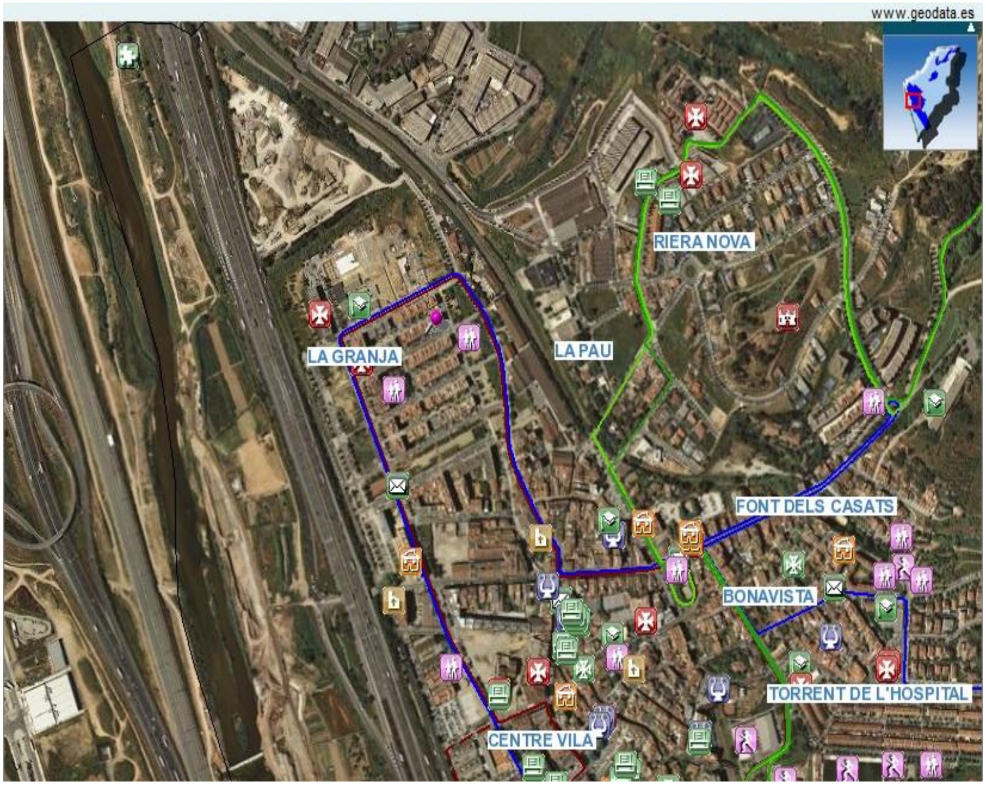


FIGURE 28. District ”La Granja”, Molins de Rei. Source: Google maps.

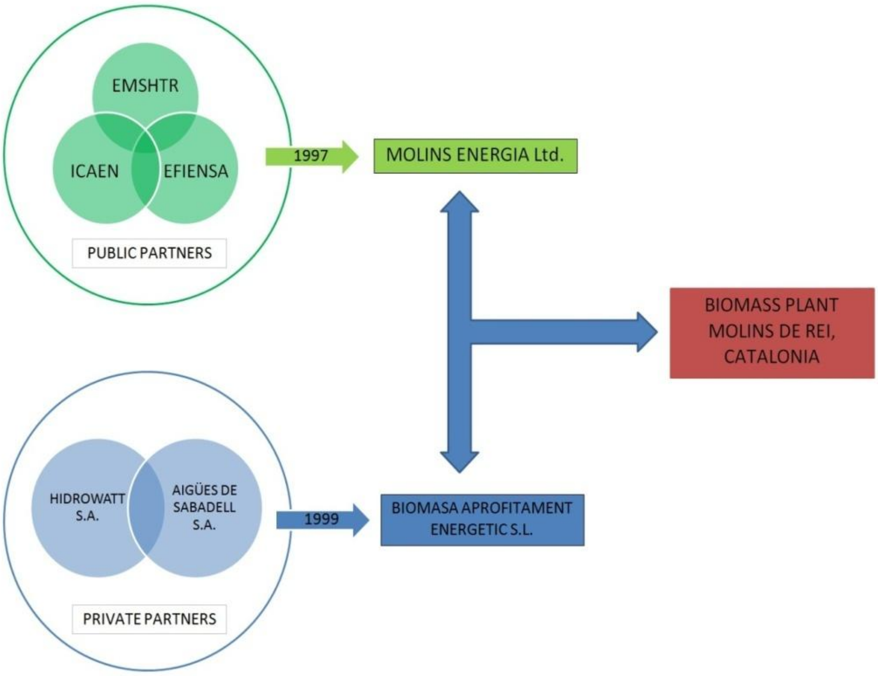


FIGURE 29. Molins de Rei biomass plant Parters.

In 1999, the three public agencies of the group launched a call for tender to select a private company and include it in Molins Energy Company, Ltd. in order to undertake the construction and management of the power plant. The contract was awarded to a consortium called "Biomasa Aprofitament Energètic, S.L. "(Biomass Energy Use, S.L.), formed by Hidrowatt S.A. and Aigues de Sabadell S.A.

4.2. Project description

The project "La Granja" Molins de Rei is a centralized network of heating and hot water produced from biomass for 695 new private and public housings. This is the first experience carried out in Catalonia connected to a central heating system powered by renewable energy area. In this regard, it should be noted that they had a very important promotional effect locally, due to the complexity of the innovative and sustainable elements included in the project.

This project was structured around three basic elements:

- Design, construction work and installation of the power plant equipped with: biomass boilers and propane gas, pumping equipment, storage tank and system management and monitoring.

- A distribution system (pipes).

- Design and management of domestic heating systems for each of the houses in the neighborhood.

In this way, users benefit from a collective to individual service facility, which is the key to the success of this initiative. This highly positive environmental concept was the central point for all promotional activities related to designing and building the project, involving the future users and all those involved identified.

FIGURE 30. Molins de Rei biomass plant. Hot water production & distribution network. Source: L.Solé.

4.3. Costs and benefits

The service of the hot water generating plant Molins de Rei began in February 2000, initially with natural gas boilers. The biomass boiler was launched in January 2001, supplying hot water to 250 homes. In November 2001, the plant had consumed 500 tons of biomass, which represented a saving of 165 tonnes of fuel a year, and had prevented the release into the atmosphere of 380 tons of CO_2.

In addition, in 2003 a total of 695 households were connected to the network of distribution and consumption of biomass was increased to 2,200 tons per year. The heat production is 6,800 MWh / year. This means a saving of 730 tonnes of oil per year and prevents the emission of 1,700 tons of CO_2.

The total investment in this project amounted to **1,622,733 Euros**, of which 456,700 Euros were provided by the European Commission through the Program THERMIE, by the Spanish Ministry of Energy and Industry through the PAEE Programme and also by the Directorate General of Catalan Energy (Directorate General of Mines and Energy of the ”Generalitat de Catalunya”). Therefore, almost 30% of the total investment has been financed by public entities.

4.4. Principles involved structures

The principles involved in this project are: the city council of Molins de Rei, EMSHTR, ICAEN and Efiensa Company, which constituted the company Molins Energia SL together with a joint venture called Biomassa Aprofitament Energètic, S.L. "(made by two companies: Hidrowatt S.A. and Aigües de Sabadell S.A.).

The city council of Molins de Rei, EMSHTR and ICAEN were the three public entities that promoted the project. Molins Energia SL is the owner of the plant and, therefore, is responsible for its management. The direct beneficiaries were the new owners or tenants of residential (private housing and subsidized housing), which were also aware of the particular characteristics of the heating system.

One of the most important elements of this project has been a focus on information to users, which may by specific devices they have in their homes, control their energy consumption. This participation in awareness and management of energy resources, can be regarded as a highly innovative and stimulating for the dissemination of knowledge on these issues.

4.5. Conclusions and consecuences

It is possible to draw important conclusions from the main elements that characterize this project. First, it is important to emphasize the collaboration and commitment of both public institutions and private enterprise, which is the key to the success of a similar initiative.

Within this project, the opportunities offered by public co-financing (easier in the case of public housing development) has contributed to overcoming this obstacle and to promoting the implementation of an innovative concept in housing. This could affect to the local or regional level, especially where there are conditions for the accumulation of fuel.

This clear public commitment (especially by municipalities) also creates a multiplier effect in terms of impact on public attitudes about environmental issues and energy saving.

A second positive element to consider is the promotion of user participation in the management of energy in their homes. through the design and installation of easy handling devices in each of the homes supplied by the district heating network.

Through these two activities from the outside it is ensured the full involvement of the local population, which represents a crucial factor for increasing the environmental awareness.

4.6. Main Features

TABLE 7. Main features Molins de Rei biomass plant.

	DESCRIPTION	Data	Units
Power	**Net biomass boiler thermal power**	2250	kW
Storage	**Biomass storage silo**	180	m³
Program	**Maximum program of work**	16	hour/day
Power	**Net thermal power boilers to gas**	817	kW
Preasure	**Work Preasure**	4	bar
Storage	**Accumulation of hot water**	325	m³
Volume · h	**Maximum flow driven**	250	m³/h
Preasure	**Pumps Height**	2.5	bar
Temperature	**Driven water temperature**	90	°C
Preasure	**Pressure losses**	2.5	bar
Volume	**Circuit volume**	125	m³
Longitude	**Distance from the district to the plant**	800	m
Longitude	**Piping network**	4734	m
Number of users		695	

TABLE 8. Consumption & Production.

Consumption & Production		
Annual biomass consumption	2200	Tones
Annual heat production	6776	MW/h

4.7. Process Line

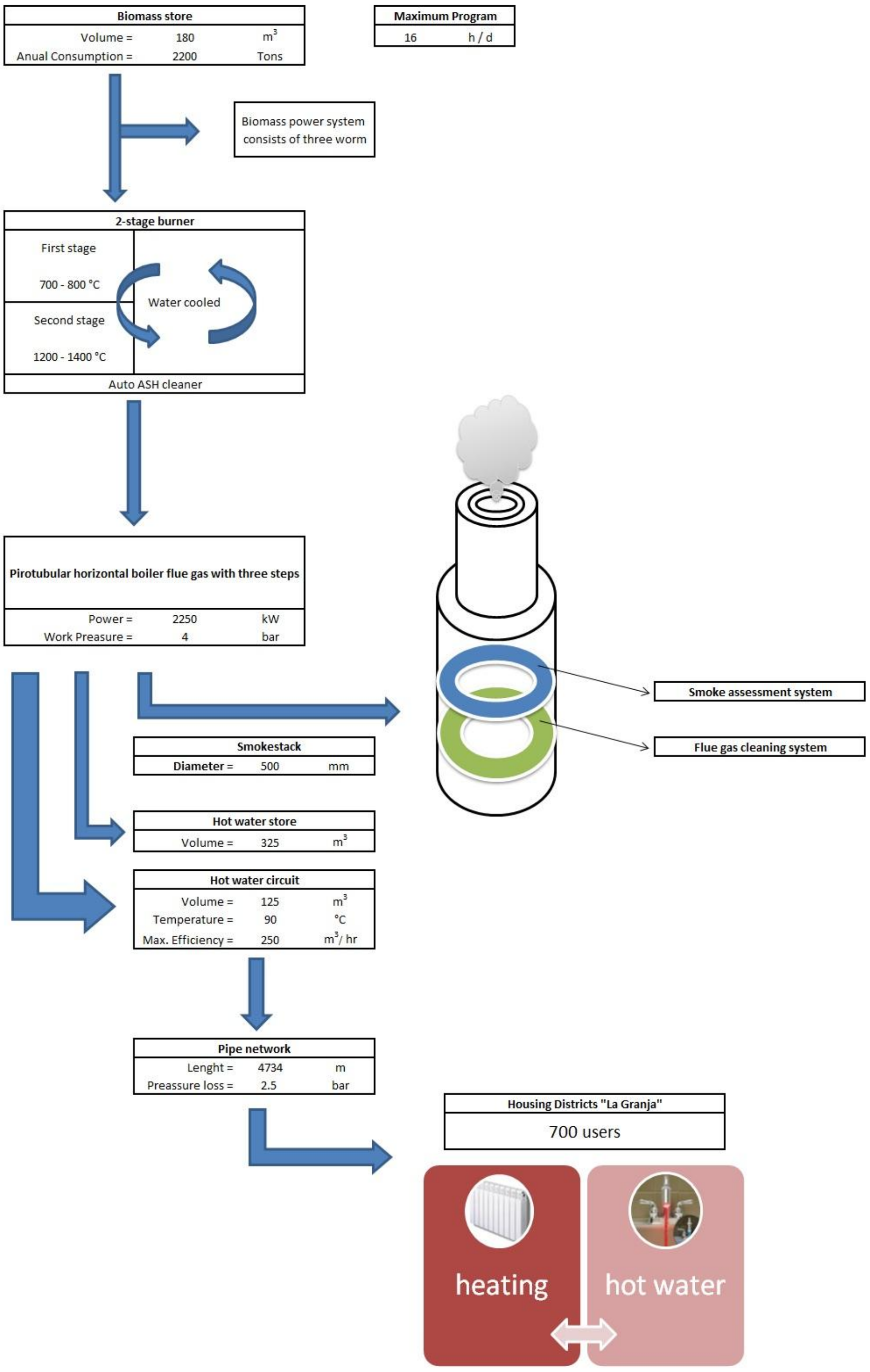


FIGURE 31. Process line, Molins Energia District Heating.

CHAPTER 5: The cooling sytem

5.1. Introduction and objective

This chapter aims to add a cooling system into the biomass plant of Molins de Rei.

After this background of knowledges and examples, the thesis is focused the way of application, the implementation of the project. The purpose is to conclude with the following results which form the last chapter of the thesis. This chapter explains the technical and economical study how to add the cooling system to the biomass plant.

Both studies are the conclusions of the comparison between diferent systems. All the proposed systems are based on the original system, based on the existing plant. Therefore, all solutions are derived from the biomass boiler used by the biomass plant of Molins de Rei.

The technical study is divided in to different parts because the system needs to be feasable. That means, all the parts that are required for the investment data of this project. Surely, with the needed economic cost.

The economical study inlcudes all the economic factors derived from the addition of the cooling system. Also the amortization of each investment is shown.

The system is defined by the following figure.

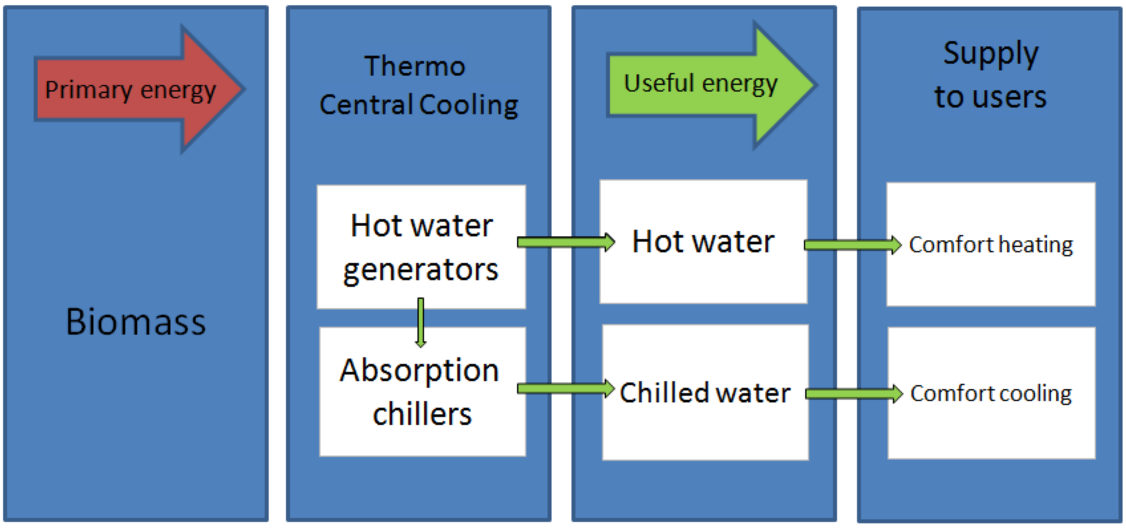


FIGURE 32. Cooling System, main parts of the process.

5.2. Technical study

5.2.1. Main parts of the system

The technical study starts considering the main parts of the new system.

Assuming that we are speaking about a biomass plant that already exists, we have to build our cooling system using the maximum number of components that the plant is already using and with the intention to find the best economic and technical solution. The system needs to feed an absorption cooling plant to produce cold water aimed to environmental air conditioning and domestic cold water, so that the set becomes a **trigeneration system.**

The centralized system technologically geared is characterized to the production and supply of heating and cooling, from a central plant to different users. This distribution is via a carrier fluid, through a thermally insulated pipe network. Thus, each user has a service independent from their climate requirements.

The DH&C system consists of three basic elements:

1. **Central heating/colling generation.** Here we find the store of biomass, the boilers for combustion, the hot water fired absorption chiller, the heat storage tanks, pumping equipment and the emergency natural gas boilers, also the automated system for management and monitoring.

2. Hot and cold water distribution network. It is formed by a network of insulated pipes with 4,734 meters of piping networks. This piping is the way to connect the hot and cold water production with the district. It is connected to the thermal substations located in each building.

3. Individual heating/colling exchange modules. These modules allow transferring the cold and hot water from the network pipes, to the final output as cooling and heating. This device allows controlling and billing the heating and cooling used by each household depending on their own needs.

FIGURE 33. Main parts of district heating and cooling.

Within this three main parts, we will proceed to study the changes and necessities that the addition of cooling need.

5.2.2. Central heating/colling generation

The thermal plant is located in a unique building, with a distance of 800 meters between the neighborhood called "La Granja" and the biomass plant. As central heating/colling production we will consider the biomass boiler that is already installed in the plant of Molins de Rei and the installation of an absorption chiller. The connection between the boiler and the absorption chiller aims at the **production and pumping of hot and cold water** to the distribution network.

Within this plant there will be located all the components and machinery necessary for the generation of hot and cold water, as well as pump units used to drive heat transporting fluid to the various points of consumption.

The power plant will operate in an automated mode, depending on the demand. Variations in demand are detected by the control system based on digital controllers located in the center and each of the thermal substations of the various buildings.

The biomass center is currently operating as a district heating system, consuming biomass to meet their needs of heating and hot water production. To cover their needs of heat, initially, in 2001, the plant had a biomass boiler of 2,250 kW and two gas boilers of 817kW of support. In 2006 they increased the biomass power adding a new biomass boiler of 2,000 kW.

FIGURE 34. Biomass boiler, Molins de Rei biomass plant. Source: L.Solé

Nowadays, the **boiler** produces **4 MW** thermal power for hot water production & distribution network. The provider of the boiler is a Spannish company called L.Solé. This company, with over 40 years experience in the design and manufacture of equipment and "turnkey" power generation systems from biomass heat(hot water, steam ...).

The biomass boiler complies with the requirements of EN 303 / 5 Boiler. Part 5; special boilers for solid fuels.

The technical specifications of the boiler is as follows:

- Biomass boiler = 4 MW thermal power (L.Solé)
- Gas boiler support = 817 kW
- Boiler efficiency: 85%
- Boiler pressure: 4 bar

The biomass raw material is: Pineapples crushed (after removing the pine nuts), fruit peels dry olive cakes, biomass from forest management, pruning, etc.

FIGURE 35. Biomass boiler, Molins de Rei biomass plant. Source: L.Solé

The systems needs the installation of an absorption chiller to the cooling production. The absoption chiller uses the hot water produced by the biomass boiler to chill the water.

The next section aims to explain the technical characteristics of the absorption chiller. The choice of the chiller is essential concerning to the requirements of cooling.

5.2.2.1. Hot water absorption chiller

Many types of absorption chillers are commercially available. Absorption chillers could be single-effect or double-effect. The double-effect chillers are more energy efficient but require higher temperature for heating and more capital costs (May 2011, Energy-Tech).

The choice of the chiller is aimed at the capacity needed to supply the system necessities. With the knowledge and help of the company BENET, it was decided to use a single effect hot water driven absortion chiller.

It is a low temperature hot water fired **single effect** absorption chiller model LT-T series. It is provided by the company called THERMAX.

Technical specifications of the chiller:

Hot Water fired Absorption chiller
Brand: THERMAX
Model: LT 42T
Capacity = 2000 kW
COP = 0.766

FIGURE 36. Absorption Chiller Machine. Source: THERMAX.

In the *Annex I* it is possible to find the technical specifications of the device (information from THERMAX). These machines have an specific requisites concerning the water quality that flows inside the system. In the *Annex I* the specific characteristics of the water are included.

Absorption chillers are the most distributed chillers worldwide. A thermal compression of the refrigerant is achieved by using a liquid refrigerant/sorbent solution and a heat source, thereby replacing the electric power consumption of a mechanical compressor. For chilled water above 0°C, as it is used in air conditioning, typically a liquid H_2O/LiBr solution is applied with water as refrigerant. Most systems use an internal solution pump, consuming little electric power only. In the operation of an H_2O/LiBr absorption chiller, a crystallisation of the solution has to be avoided by an internal control of the heat rejection temperature in the machine.

The main components of an absorption chiller are shown in the following figure.

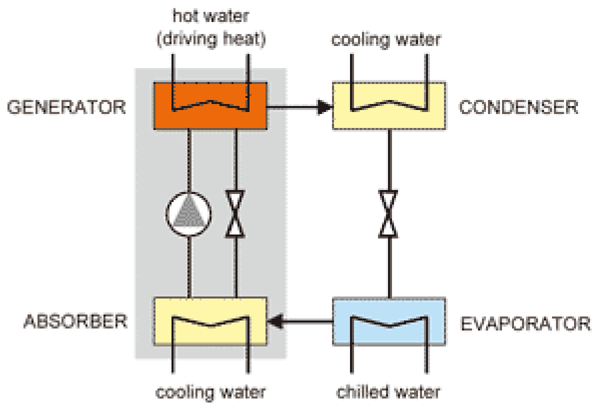


FIGURE 37. Main components of the absorption chiller.

The cooling effect is based on the evaporation of the refrigerant (water) in the evaporator at very low pressures. The vaporised refrigerant is absorbed in the absorber, thereby diluting the H_2O/LiBr solution. To make the absorption process efficient, the process has to be cooled. The solution is continuously pumped into the generator, where the regeneration of the solution is achieved by applying hot water. The refrigerant leaving the generator by this process condenses through the application of cooling water in the condenser and circulates by means of an expansion valve again into the evaporator.

The required heat source temperature is usually above 80°C for single-effect machines and the COP is in the range from 0.6 to 0.8.

The figure below shows a schematic illustration of a single-effect absorption cycle, where the relative position of the heat exchangers of the cycle indicates their operating pressure and temperature.

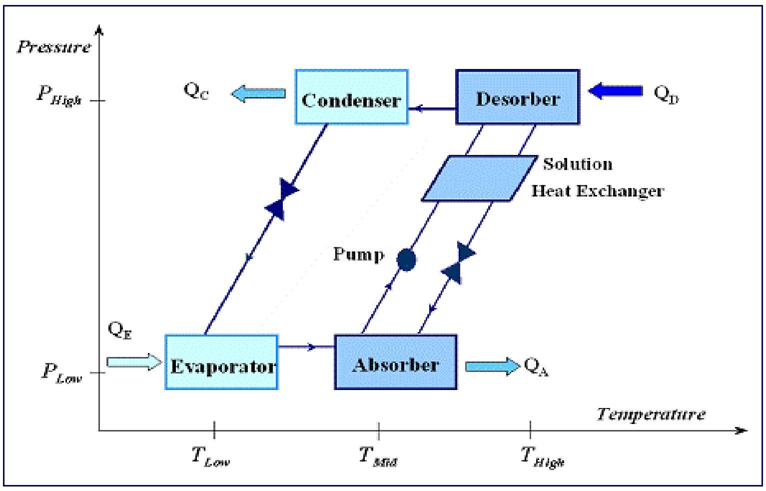


FIGURE 38. Single-effect absorption cycle. Source: University of California, Irvine.

The cost of this machine is 159,200 €. This price has been achieved thanks to a confidential budget, provided by the company BENET, for the realization of this thesis.

$$\boldsymbol{Cost\ of\ the\ Absorption\ Machine} = 159{,}200\ €$$

This price includes a big description of the machinery: General features, main components, controls and safeties, scope of the supply, scope of the supply purchaser, performance criteria. This contract requires special terms and conditions.

5.2.3. Distribution network

Once installed the absorption chiller it is necessary to ajust the **piping network** to adapt the system for the cooling piping. The adition of cooling means that it is necessary to install new cold water pipes, from the biomass plant to the housing district, with the corresponding cost.

Once generated hot and cold water shall be distributed to various places where the buildings are located through a network of pre-insulated pipes to prevent losses. The distribution network consists of a **four-pipe system**, with independent circuits for cold and heat.

The collectors of hot and cold water from the biomass plant are connected with the housing districts by lines, lying on the different service yards of each customer building. There is a branch at the entrance to each home through a switching and control panel of the respective hydraulic circuits.

The internal circuitry of cold and hot water for heating and cooling is linked directly to the relevant community collectors.

Companies specializing in the design and assembly of these circuits offer individual standard modules, pre-assembled in the factory according to the requirements of each case.

The following figure illustrates the layout of a simple form, with direct connection from the manifolds community to the hot and cold water pipes for a standard dwelling of a multifamily building. The air conditioning is executed with fan coil units, one per user.

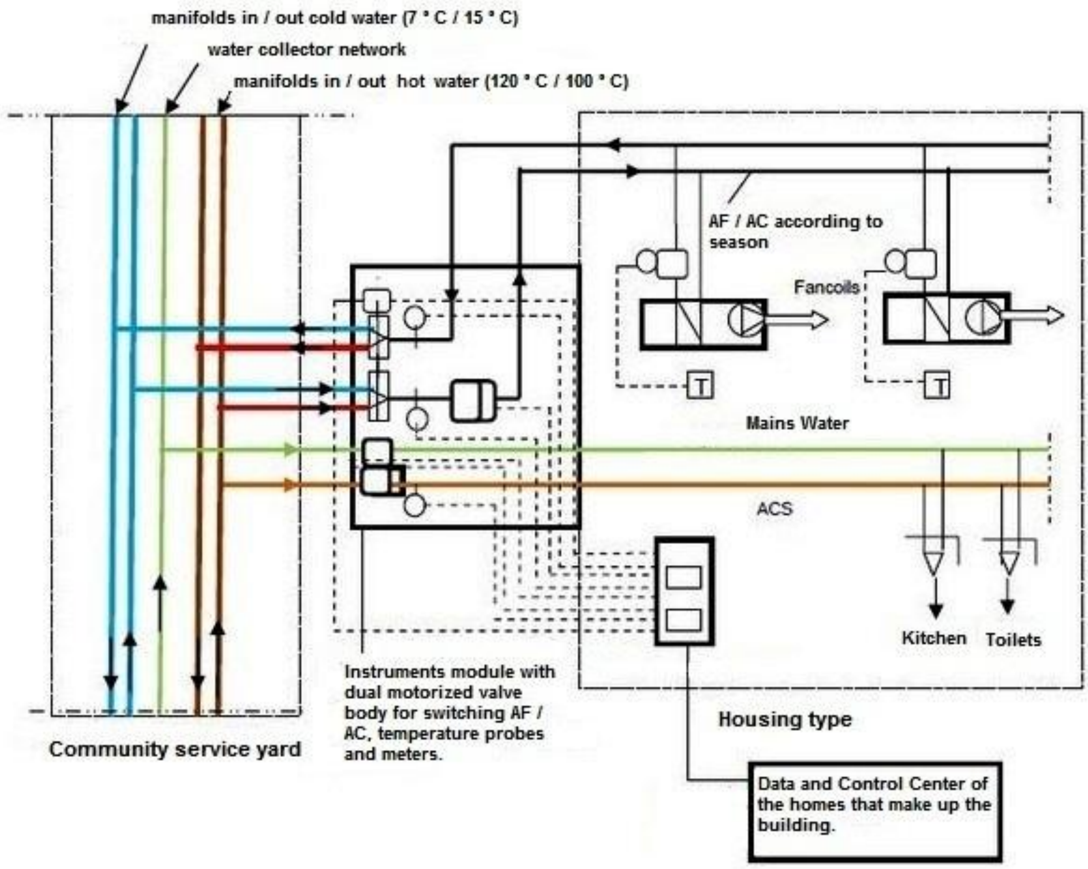


FIGURE 39. Conceptual Network design.

In the *Annex I* it is shown a conceptual design of the main solution. Also a second option has been designed in order to save the possible costs of the cold water pipings, with the installation of small absorption chillers that could be installed in each building of the housing district. Anyway, the main solution that this thesis proposes is the installation of the chiller explained before.

As the figure 39 shows, the water lines AF / AC to the fan coil units is a 4-pipe model (outward / return for each condition cold and hot) that connects the two members to the motorized diverter valves, moduled by the housing instruments. The valves are used to switch both circuits, referred as a single 2-pipe internal circuit, which supplies the hot or cold water to the fan coil, depending on the preset system. Fan coils in the same housing can be manually controlled from the control panel itself, or automatically by the thermostatic control.

The use of 2-way motorized valve regulates the flow of water circulating through the room controlled by a thermostat. Also regulates the variable flow in the manifolds community, and adjust the speed of the pumps. Therefore the power consumption could change depending the function of the overall needs of the building.

The distance between the biomass plant and the housing district is 800 m. The distribution of hot water generated has a length of nearly 2,400 m.

We will suppose the same length for the cold water circulation:

$$Cooling\ piping\ network = 2{,}400\ \ [m]$$

5.2.3.1. Hot water pipes specifications

The distribution of hot water generated has a length of nearly 2,400 m. It consists of stainless steel pipes with a polyurethane coating. The driven water temperature is about 90 º C. With a maximum flow of 250 m^3/h. And 2.5 bar of pressure. This piping already exists, so we will not consider any increase into the final amount.

- Network volume: 125 m^3
- Maximum flow rate: 250 m^3/h
- Pressure: 2.5 bar
- Network diameter: between 60 and 273 mm with polyurethane insulation.

5.2.3.2. Cold water pipes specifications

The cold water circuit of each house arrives from the manifolds community with variable flow in both paths. The temperature of the cold water outlet generation is 7 º C, when reaching the terminal fan coil units it is around 8 - 9 º C, approx., (standard operating temperature). This design of piping is aimed to achieve the minimum allowable losses of temperature between the primary and secondary circuits.

In order to limit the temperature losses, the cold water pipes need special conditions.

This type of driving has a number of advantages over insulated pipes in place by the traditional method:

-Minimum thermal losses
-Quick installation (less man power or labor)
-Long life and minimum maintenance
-Minor works (directly buried pipe trench)
-Long life and minimum maintenance.

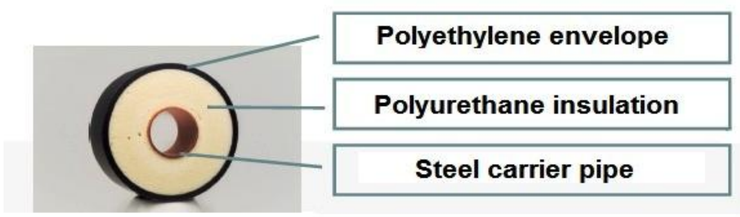


FIGURE 40. Cold water pipes.

The cold water pipes have special conditions depending on the pressure of the system. The absorption chiller has a maximum working pressure of 785 kPa(g).

The price of the cold water pipes that will meet this requirements (according to the company BENET) can be assumed approx. from 110 € per meter.

$$\boldsymbol{Cold\ water\ pipes\ cost} = 110\frac{€}{m} \times 2400\ m = 264{,}000\ €$$

5.2.3.3.Thermal substation

In the various buildings there are located thermal substations, consisting of a heat/cold exchange system, where the heat and cold water will be transferred to the terminal elements of the buildings. The thermal substations control the measurement of consumption for each building.

FIGURE 41. Thermal substation.

Each house has in the kitchen or laundry, a compact installation which consists of two small heat exchangers, where water heat distribution network gives its heat to the heating, cold water to cooling or hot water production of the building.

5.2.4. Individual heating/cooling exchange modules

To further simplify the schemes, we will provide a 4 pipe **fan coils** as air conditioning units of housing, a single team roof, air distribution through ducts to all houses, controled by devices installed in each house wall.

Depending on the characteristics and conditions of the building and its location, the designs can allow other components, as alternatives to the fan coil, like hot water radiators, underfloor heating, etc.

In the design will be provided the installation with fan coil units.

5.2.4.1. Fan-coil

Fan-Coil is an air conditioning system of mixed type. It is advantageous in buildings where it is necessary to save as much space as possible. As a supplement to centralized systems that requires large areas to install the equipment.

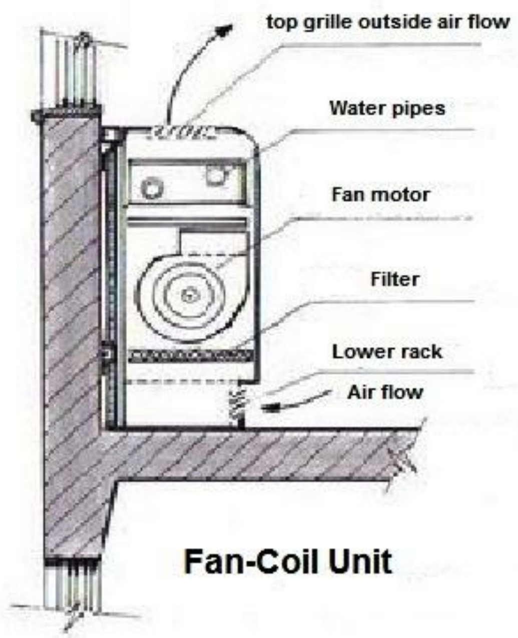


FIGURE 42. Fan-Coil Unit. Source: Wikipedia.

- **Single Fan Coil Units**, located in each room to be conditioned, to which the water comes. The air is treated and driven to a local fan through a filter. Thus, when the air is cooled it is sent to the transmitting ambient heat of the water that returns along the circuit.

The instalation of 4 pipes fan coils allow to the same system, to provide heating and cooling. This type of fan coil needs 2 batteries, for colling and heating, which are connected to 2 air-water devices acting according to the local needs.

In all cases it is required a detailed study of solutions, from centralized generation of hot and cold water, technically and economically it should be optimized the performance of terminal equipment, to avoid duplication of hydraulic circuits, free space, etc.

The model studied here is from the brand CIAT. It is a ceiling fan coil, a four-pipe system, with distribution channels model Major NCH 325 "CIAT".

Features on cold cycle:
Total cooling capacity: 1.51 kW Sensible cooling capacity: 1.51 kW Water flow: 0,302 m³ / h Pressure drop of water: 34.5 kPa
Heat-cycle characteristics:
Heat output: 0.97 kW Water flow: 0,066 m³ / h Water pressure drop: 0.8 kPa Sound power level: 48 dBA Airflow: 230 m³ / h Air pressure: 10 Pa *This data is calculated considering our system conditions. In the annex I it is possible to find the specifications sheet.*

$$\boldsymbol{Fan\ Coil\ unitary\ cost} = 869{,}12\ €$$

It will be necessary to measure the number of units actually executed according to the specifications of the project. In our calculations we assume that the number of units equals the number of users residing in the neighborhood "la Granja" located in Molins de Rei.

The number of users is 695:

$$\boldsymbol{Fan\ coil\ total\ units\ cost} = 695\ users \times 869.12\ € = 603{,}755\ €$$

5.2.5. Operation time of the system

The working time of the plant is depending on the time of the year. Because of this, it is necessary to consider different consumptions, accordingly if it is summer or winter.

If the outdoor temperature is lower than the temperature inside the building, the system transfers heat to the outside through the walls by convection. Also, the temperature is cooled by the air intake as a result of the renovation and infiltration, etc. The existence of staircases affects the air circulation, and other complex circumstances, typical of modern buildings tend to reduce indoor air temperature. Moreover, lighting, appliances that are turned off and cooled over night, etc., generate loads of laborious calculations which are difficult to obtain from the indoor air temperature.

Normally, the heating of residential buildings do not work 24 hours a day. In Spain, the heating period takes from Octover until March. The cooling period takes from April until September per day.

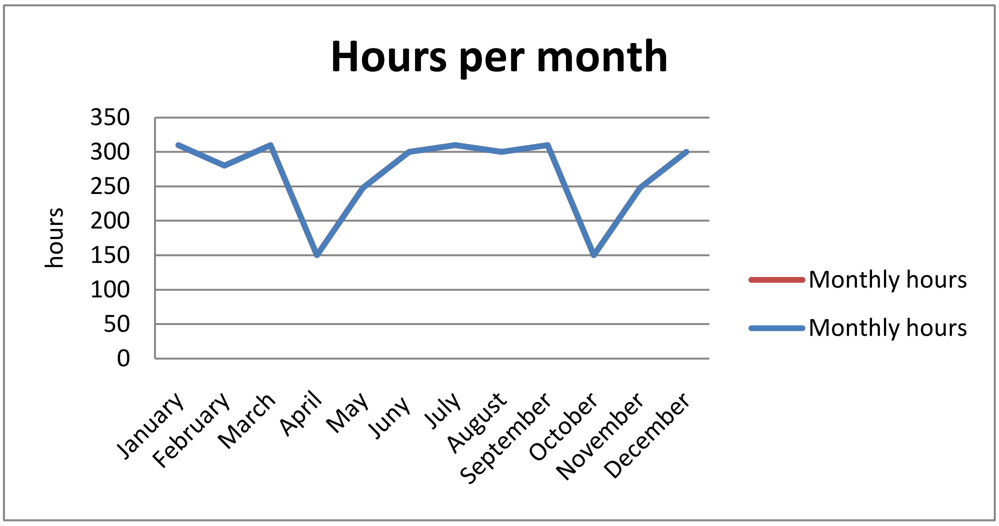
Considering that, we have next the table that explains the hours of operation according to each month. As the main data we will have the number of hours per year.

TABLE 9. Monthly working hours.

Monthly working hours				
Month	**Require-ment**	**Daily hours**	**Days / month**	**Hours / month**
January	heating	10	31	310
February	heating	10	28	280
March	heating	10	31	310
April	cooling	5	30	150
May	cooling	8	31	248
Juny	cooling	10	30	300
July	cooling	10	31	310
August	cooling	10	30	300
September	cooling	10	31	310
October	heating	5	30	150
November	heating	8	31	248
December	heating	10	30	300

	Hours of operation hours/year
Months heating	1598
Months cooling	1618
Total hours per year =	3216

TABLE 10. Monthly working hours graphically.



5.2.6. Raw material characteristics

The raw material for the boiler can be various types of biomass, as almond shells, olive pomace, crushed pineapples and forest-chips. This raw material have properties expresed as kJ/kg and €/kg.

The main data of the raw material for biomass boilers is the heating power or PCI. This table below relates the power to the weight, so the value is given according to the weight. In this way we can approximate the cost of biomass, because we know that our boiler consumes almond shells, olive pomace and forest-chips and more. We have taken the data from each of these components and have made an arithmetic mean to determine an estimated average of the consumption.

TABLE 10.Biomass heating power.

BIOMASS HEATING POWER

MEDIUM

FUEL	*PCI kJ / kg
Wet bagasse	10500
Dry bagasse	19200
Peanut shell	17800
Rice husks	13800
Pulp	16500
Bark drained	5900
Cane cossettes	4600
Dry wood	19000
Green wood (*)	14400
Wheat stubble	12500
Barley stubble	13400
Moist sawdust	8400
Dry chip	13400
AVERAGE =	9269,230769

MAXIMUM

FUEL	*PCI kJ / kg
Almond shells	36800
Walnut shell	32000
Rice husk	15300
Sunflower shell pipe	17500
Wheat shell	15800
Pine Bark	20400
Cork	20930
Olive orujillo	17900
Grape marc	19126
Paper	17500
Jara (8% moisture)	18900 (P.C.I.)
AVERAGE =	15058,15385

FINAL AVERAGE = 12163.69 KJ/kg

*The PCI quotes the net calorific value. Is the net amount of energy that is developed from the combustion of 1 kg of fuel with its actual water content in the actual conditions of use as biomass.

5.2.7. Energy Consumption

The energy consumption is one of the points for checking the feasability of the system. The total consumption is calculated per year, as a result of adding the cooling and heating consumption.

$$\text{Annual primary energy (KWh / year)} = \frac{\text{Annual energy consumption (KWh / year)}}{\text{Boiler performance}}$$

TABLE 11. Energy consumption.

ENERGY CONSUMPTION				
Month	**Hours ON**	**Boiler output (80%) kW**	**Absorption power (COP 76.6 %) kW**	**Energy (kWh / month)**
January (heating)	310	3200	OFF	992000
February (heating)	280	3200	OFF	896000
March (heating)	310	3200	OFF	992000
April (cooling)	150	3200	1532	709800
May (cooling)	248	3200	1532	1173536
Juny (cooling)	300	3200	1532	1419600
July (cooling)	310	3200	1532	1466920
August (cooling)	300	3200	1532	1419600
September (cooling)	310	3200	1532	1466920
October (heating)	150	3200	OFF	480000
November (heating)	248	3200	OFF	793600
December (heating)	300	3200	OFF	960000
TOTAL =	3216 hours			12,769,976 KWh

TABLE 12. Final energy demand.

FINAL ENERGY DEMAND				
	Hours hours/year	Boiler output kW	Absorption power kW	Final energy demanded kWh/year
Heating	1598	3200	0	5,113,600
Cooling	1618	3200	1,532	7,656,376
			Total =	12,769,976 kWh/year

$$\text{Annual biomass consumption (kg / year)} = \frac{\text{Annual primary energy (KWh / year)}}{\text{Calorific (KWh / kg)}}$$

*1KWh = 3600 KJ

$$\boldsymbol{KJ\ demanded} = 12770000\ KWh \times \frac{3600\ KJ}{1\ KWh} = 4.6 \times 10^{10}\ KJ$$

$$\boldsymbol{Annual\ tons\ of\ biomass} = 4.6 \times 10^{10}\ KJ \times \frac{1\ Kg}{12163.69\ KJ} = 3{,}781{,}747\ Kg$$

$$\boldsymbol{Annual\ tons\ of\ biomass} = 3{,}782\ Tones$$

TABLE 13. Biomass consumption.

BIOMASS CONSUMPTION			
	MWh/year	**KJ/year**	**Tones/year**
Annual Energy consumption =	12770	4.6×10^{10}	3,782

5.2.8. Biomass storage volume

$$\text{Daily biomass consumption}\left(\frac{\text{kg}}{\text{day}}\right)=\frac{\text{Annual biomass consumption (kg / year)}}{\text{Number of days (days)}}$$

$$\text{Daily biomass consumption}\left(\frac{\text{kg}}{\text{day}}\right)=\frac{3782000(\text{kg / year})}{365(\text{days})}=10{,}361.64\left(\frac{\text{kg}}{\text{day}}\right)$$

$$\text{Biomass consumption volume}\left(\frac{\text{m}^3}{\text{day}}\right)=\frac{\text{Daily biomass consumption (kg / day)}}{\text{Density (kg/m}^3)}$$

*Density = 700 kg/m^3 (normal density for pellet)

$$\text{Biomass consumption volume}\left(\frac{\text{m}^3}{\text{day}}\right)=\frac{10361.64(\text{kg / day})}{700(\text{kg/m}^3)}=14.802\left(\frac{\text{m}^3}{\text{day}}\right)$$

$$\text{Silo volume }(\text{m}^3)=\text{biomass consumption}\left(\frac{\text{m}^3}{\text{day}}\right)*\text{duration (days)}$$

$$\text{Silo volume }(\text{m}^3)=14.802\left(\frac{\text{m}^3}{\text{day}}\right)*31(\text{days})=458(\text{m}^3)$$

The current silo has a volume of 180 m^3 so it is going to be necessary to expand the biomass store. The expansion should be of 280 m^3 . This kind of ampliation is not going to be reflected in the economic study. In any case, its construction would be an expense of the company in charge of the plant.

5.2.9. Comparison Heating – Heating+Cooling

The main point of the thesis is to demostrate the feasability of the cooling addition. The next figure shows the final consumption and production of the two systems.

TABLE 14. Biomass heating power.

Heating		
in	**Consumption =**	2200 Tones per year
out	**Production =**	6800 MWh/year

Heating+Cooling		
in	**Consumption =**	3782 Tones per year
out	**Production =**	12770 MWh/year

5.2.10. RITE (Real Decreto 1027/2007)

Nowadays, the Spanish law is regulating the operation of the cooling systems. It is part of the RITE (Real Decreto 1027/2007). This law mandates the periodic evaluation of the performance of the cold-generating equipment. The maintenance company carry out a regular assessment and evaluation of the performance of refrigerating unit according to the following figure:

Medidas de generadores de frío	Periodicidad	
	70 kW < P ≤ 1.000 kW	P > 1.000 kW
1. Temperatura del fluido exterior en entrada y salida del evaporador	3m	m
2. Temperatura del fluido exterior en entrada y salida del condensador	3m	m
3. Pérdida de presión en el evaporador en plantas enfriadas por agua	3m	m
4. Pérdida de presión en el condensador en plantas enfriadas por agua	3m	m
5. Temperatura y presión de evaporación	3m	m
6. Temperatura y presión de condensación	3m	m
7. Potencia eléctrica absorbida	3m	m
8. Potencia térmica instantánea del generador, como porcentaje de la carga máxima	3m	m
9. CEE o COP instantáneo	3m	m
10. Caudal de agua en el evaporador	3m	m
11. Caudal de agua en el condensador	3m	m

m: una vez al mes; la primera al inicio de la temporada; 3m: cada tres meses; la primera al inicio de la temporada

**'m' means once per month, the first reading every season start*
'3m' means every three months, the first reading every season start.

FIGURE 43. Biomass heating power.

This new law requires the calculation of three concepts. In this case the power > 1000 kW means that the first reading has to be at the start of every season. The concepts to be calculated are: the electrical power absorbed, the instant heat output and the COP calculation. In the next three sections the calculation of each one is shown.

- **Electrical power absorbed [W]:** This is the power consumed by the compressor, measuring and registration is required.

- **Instant heat output [W]:** This is the power generated in relation to the time unit produced by a system of hot and cold water generation.

- **COP Calculation[no unit]:** The relation between the heating/cooling capacity and the power effectively absorbed by the unit which is called COP.

The COP is a measure of energy efficiency and it is calculated as the ratio of the instantaneous heat output and the power consumed.

5.3. Economic study

The installation of the district heating and cooling takes place from the user's point of view, mainly to save money on energy costs. For economic analysis of the feasibility of the cooling installation it is required to determine the savings in energy costs and the value of the investment required. Furthermore, it is necessary to study the biomass consumptions after installing the cooling system.

5.3.1. Investment cost

For calculating the cost of the investment the break down list of the investment is shown in the next table which explains the diferent amounts.

TABLE 15. Investment cost.

Investment Cost			
Description	**Characteristics**	**Unit cost**	**Total Cost**
Hot water absorption chiller	1	159,20 €	159.000,00 €
Distribution Network	1600 meters of pipes**	110 €/meter	264.000,00 €
Fan Coil Units	695 units*	869,12 €	603.755 €
TOTAL			1.026.755,00 €

**number of users*

**cold water piping

In order to do the next calculations we will introduce a new quantity of the final investment by adding a possible grant. This supposition is very successful considering that we are building a suistanable system that works with a renewable energy. The system has been designed concerning the effincency of energy and cost.

Assuming that we will consider a 30% grant, for example, provided from the public entities.

TABLE 16. Investment cost with and without grants.

	Cost
Total investment	1.026.755,00 €
Investment with 30% of grants	308.027 €

5.3.2. Monthly fee of the cooling investment

The Monthly fee is the amount that beneficiaries would have to contribute to the amortization of the investment. The company that runs the plant will be in charge of the maintenance and management. This company will charge a monthly quota from each user according to the consumption of the biomass, in relation to the time of year.

TABLE 17**.** Monthly fee of the investment.

Description
This calculation is about recouping the investment focused on the number of users, because they are the final consumers of that service. In order to achieve the efficiency between price and use. Consequently, 695 users. The Monthly fee in 10 years between 695.

	Monthly fee
Monthly fee to recoup the investment in 10 years	12,31 €/month
Monthly fee to recoup the investment in 10 years with GRANTS*	3,7 €/month

5.3.3. Price of biomass

The price of biomass is one of the most decisive factors for the viability of a project. We must not forget that the term biomass covers the full extent of any fossil fuel. For our project, as in any other case, we will consider the type of biomass consumed by the boiler.

According to the data taken from the website of the Generalitat of Catalonia, in an article of PRODESA company, sponsored by the Ministry of Spain specializing in biomass pellets, we can approximate the cost of biomass at €**50 / tonne.**

The next figure shows the evolution of the prices of fuel oil compared with two biomass fuels for household use, such as the pellet and olive pits.

As you can see, the gap in the price of fuel oil compared to the latter two fuels is growing. Prices reflected on this chart correspond to small consumers, up to 2000 L, mainly for domestic use.

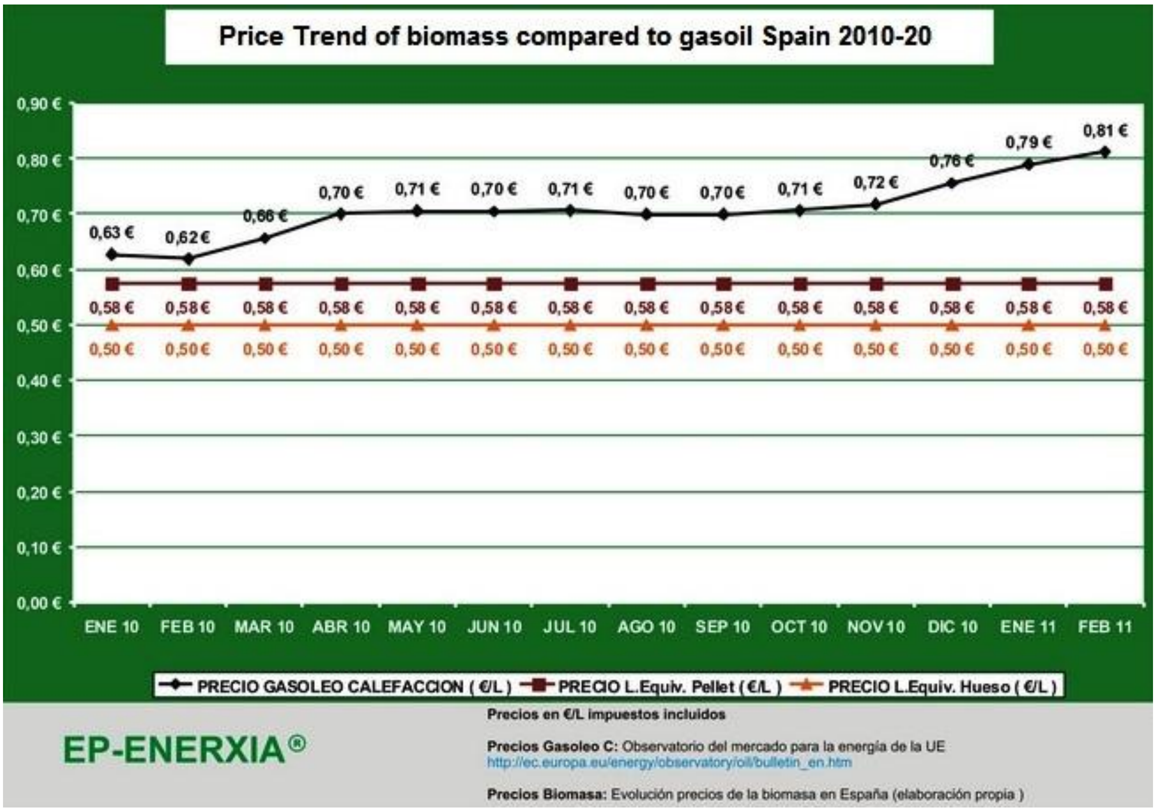


FIGURE. 44. Price trend of biomass. Source: EP-ENERXIA.

5.3.4. Biomass cost

$$\text{Annual cost of biomass} \left(\frac{\text{tons}}{\text{year}}\right) = \text{Annual biomass consumption} \left(\frac{\text{tons}}{\text{year}}\right) * \text{biomass average price} \left(\frac{€}{\text{tons}}\right)$$

$$\text{Annual cost of biomass} \left(\frac{€}{\text{year}}\right) = 3782 \left(\frac{\text{tons}}{\text{year}}\right) * 50 \left(\frac{€}{\text{tons}}\right) = 189{,}100 \left(\frac{€}{\text{year}}\right)$$

5.3.5. Monthly fee with cooling

This calculation is to realise the monthly amount that the users must pay for the services of heating and cooling during all season. This calculation is is the result of dividing the total cost of biomass between the users, in our case 695 and also divided by 12 months of the year.

TABLE 18. Monthly fee of the fuel consumption.

MONTHLY FEE		
Anual system Cost	189100	€/year
Monthly system Cost	15,758.333	€/year
Monthly fee for 695 users = 22.6738 €/month		

5.3.6. Economic Comparison between Heating & Cooling and only heating.

The next table shows the comparison between the two systems in order of consumption, production, investment and annual fee. On the one hand is shown a biomass district heating system (DH) plus an individual AC (1000€) for each user. On the other hand is shown a district heating & cooling both produced by biomass.

TABLE 19. Final results.

Heating+Indivual AC			Heating and cooling		
Biomass consumption	2200	Tons/year	**Biomass consumption**	3782	Tons/year
Production	6800	MWh/year	**Production**	12770	MWh/year
Investment	2,317,733	€	**Investment***	2,649,488	€
Annual Fee	158.268	€	**Annual Fee**	272.0856	€

5.3.7. Design rejected. Small chiller.

During the choice of the chiller was suggested a solution which turned out to be less effective than the final one. The idea was to install small chillers in the housing district considering the piping savings. We did the calculation to check the posibility of install a 105 kW chiller from the brand YAZAKI.

The chiller has the following features:

Small chiller	
Brand	YAZAKI
Model	WFCSC30
Capacity	105 kW
Price	57.822,00 €

**info from ABSORSISTEM S.L.*

The idea is to calculate the solution shown in the *Annex I*. Considering 110 €/m the cost of the cold pipes and 2400 m of long. In order to that data it is easy to show the result of the decision.

Features			TOTAL COST
Cold pipes cost	110 €/m	1600 m	176.000 €
Small chiller cost	57.822 €	694 users	40.128.468 €

Considering this calculation, the results come to the conclusion that this solution is only available for long distances between the biomass plant and the housing district.

CHAPTER 6: Conclusions

6.1. Introduction

After studying the functioning of the system, and analyzing the costs that derives from the insertion of refrigeration, the thesis concludes with a final conclusion based on the results.

In this chapter, the thesis will conclude with an assessment of the results and lessons learned in the previous chapters. The conclusion is made on one hand, in relation with the technical section and on the other hand, in relation to the economic section. In addition, all ends with my personal opinion based on biomass and global energy issues.

6.2. Technically

The technical feasibility of the project has been studied based on the most crucial factors of the insertion of the cooling system to the existing biomass system.

The most critical points are: the power required for the viability of the system, the consumption of biomass needed, and finally the application of the process of heating and cooling in the residential district.

The power demand has been calculated as a function of operating hours. Depending on the season of the year the system has a varied consumption. This consumption is based on the climatic conditions of the study, Catalonia.

The demand of energy is the result of adding the power consumed by the boiler plus the absorption chiller. The set has a consumption of about twice MWh / year than a system based simply on heating. As a direct consequence of this, biomass consumption also doubles. The warehouse of the biomass should adapt to new requirements, would need an expansion of its volume.

The network of pipes needed reforms. There is a need to adapt the circulation of cold water from the central housing. These pipes have special structure constructions to prevent heat loss. Their diameter is a function of the pressure they endure.

The installation of fan coil units, requires an increase in the budget but this is the most effective solution for the system. Such devices are the direct application of hot and cold water, once distributed from the central shaft housing. Its function concludes with the heating and cooling in each of the houses. These devices are controlled by the user with the help of a thermostat. In addition, each block of the houses has thermal substations, regulated by valves, which are responsible for controlling the passage of hot or cold water depending on the time of the year. These thermal substations are also responsible for the control of energy by regulating its consumption.

One of the most difficult decisions to make is the power to install a function based on demand. In this project the demand has been calculated taking into account the weather. This calculation must take into account the user demand. Unable to have these data, the most reliable approximation is to take into account the hours required according to the month of the year.

Technically, we can conclude that the system is viable.

The most controversial point would be the supply of biomass. Considering biomass, nowadays, is not a standard fuel. For the installation of a system with these characteristics, with almost **13 GWh / year**, it would be necessary to sign a contract with any biomass supply company. This company should guarantee the supply of fuel.

It is necessary to comment that the use of biomass involves the use of renewable energy. Therefore, the emission of CO_2 produced by a system of these characteristics issues a sustainable pollution, with a corresponding respect for the environment.

Technically I would like to add that currently, there is an energy dependence that determines the price of energy and this is a direct consequence of the monopoly of oil. This dependence creates constraints in the development of alternative systems to oil.

Today, we know more than enough, that oil stocks are reaching the limits of their supply. Global consciousness about the end of oil and its consequent pollution against sustainability makes awareness is raised and innovative new forms of energy are required. If we analyze the twentieth century, humanity has focused on the conquest and exploitation of oil, with considerable consequences. It is now deep in the twenty-first century when renewable energy is gaining importance due to its sustainability with the natural conditions of the planet.

6.3. Economically

Economically, the argument has two key points. On the one hand, the investment required for the installation of cooling, involves the purchase of new machinery and adjusting the distribution network. On the other hand, the cost is derived once the installation starts to run. The summary of the economical issues could be summed up in two groups, one group that would be the costs of investment and a second group of costs resulting from the operation.

The investment required for the viability of the system has been calculated only taking into account the wider costs. Assessed costs are formed by the absorption chiller, the network of new pipelines and the installation of the devices in homes. The sum of these components form the total investment for installing the system. The final price amounts to €**1,026,755**. If we consider that the service has about 700 users, the investment to pay in ten years is considerably smaller. The thesis includes the possible grants for the project due to their conditions. According to the new Energy Directorate, designed for better energy efficiency it is shown that biomass is an optimal solution for residential air conditioning.

Operating costs have been calculated taking into account the price of fuel and power requirements of the system. The functionality of the system produces an annual cost of approximately **€189,100**.This cost may vary with the price of biomass. Currently, both in Catalonia and the rest of Spain, the price of biomass is standardized and is maintained without significant increases. The supply of biomass varies depending on the location of each system. Furthermore, biomass has some different characteristics according to the area. The price of biomass depends on the type of fuel, each fuel has a thermal output based on the level of humidity and density. Also the price is affected by the amount that must be provided, differentiating autonomous consumers of consumption by a residential district.

Economically, we can conclude that the system is viable.

Although the economic study is not made in detail, not taking into account the VAT and the costs of labor, the bill per month that has been completed shows that the investment is proportional to the earnings of the use.

It could be said that the investment of a district heating and cooling, becomes feasible, more possible and less privileged for people, in order to meet the needs of air conditioning at home. Considering the savings from the individual air conditioning that costs around €1000 plus the mantenance.

6.4. Summary

This section discusses the most important points, focusing on the feasibility of the system. Here are just the advantages and disadvantages.

6.4.1. Advantages

- Reduction of CO_2 emissions to the atmosphere.
- This type of system involves the use of own resources of the nations, contributing to the energy independence of each locality(village, township...).
- Possible creation of more jobs in the area of installation. Workers contribute to the supply of biomass energy supply with the consequent care of forests.
- Rationing of the energy consumption according to the requests of the user.
- The cost of the service, combining heating and cooling is considerably reduced.
- The cost of maintaining the system is managed by the company that is supplying the energy.
- Generally, all investments through sustainable facilities have the financial support of public institutions. That is because they contribute to the development of renewable energy and help fulfill the requirements set by the global energy policy.
- Importance of polygeneration from the following points of view: energy, economics and environment.

6.4.2. Disadvantages

- The biomass supply is varied depending on the climatic zone.

- The price of biomass varies depending on its quality, but also is increased by the distance between the power station and power supply. The consumption of the trucks transporting biomass are included in the price and may influence it significantly.

- The efficiency of the Absorption systems become dependent on this type of cooling systems.

- The machinery for collection of biomass has a high price which requires an investment in economic capital.

- The volume of biomass makes it expensive to transport and handle..

- All centralized system conditions sometimes the user needs.

- The chemicals used by the Absorption systems consider the possibility of problems of crystallization of lithium bromide, lead compounds of these machines.

6.4.3. Solutions to boost biomass

- Involving forest owners to use biomass through organizational structures that can guarantee the supply.

- Dissemination of techniques and appropriate technologies to use biomass and, in turn, this could be incorporated by the forest service enterprises.

- Contributing to rural development by generating employment, forestry utilities through the installation of plants of forest biomass.

- Contributing to the capitalization and sustainability of forests in Southern Europe, makinga more integrated management of forest resources and appreciating products considering waste.

- To collaborate in eliminating obstacles to overcome deficiencies that prevent the use of forest biomass as a renewable energy source.

- To cooperate in reducing dependence of fossil fuels in energy production.

6.5. Final Conclusion

Biomass is an energy source that depends on the exploitation of its resources. The feasibility of its use is directly dependent on natural resources in the area. That sets the biomass price.

Considering that Catalonia is the area where the system would be implemented, it could be said that their high temperatures in summer and low in winter, would cause a constant use of the boiler.

The results of the thesis could be conclude saying that the district heating and cooling is firstly, giving use to the biomass and secondly, producing savings in order of pollution and cost.

Biomass cogeneration is widely used for district heating applications in central and northern Europe. Biomass trigeneration on the other hand, constitutes an innovative renewable energy application. In this work, an approved United Nations Framework Convention on Climate Change baseline methodology has been extended to allow the examination of biomass trigeneration applications.

South-western Europe is one of the regions with highest biodiversity and with greatest capacity of production of Europe. However, it is also one of the regions with the highest number of forest fires, the widest burnt surface and the highest vulnerability to plagues and diseases.

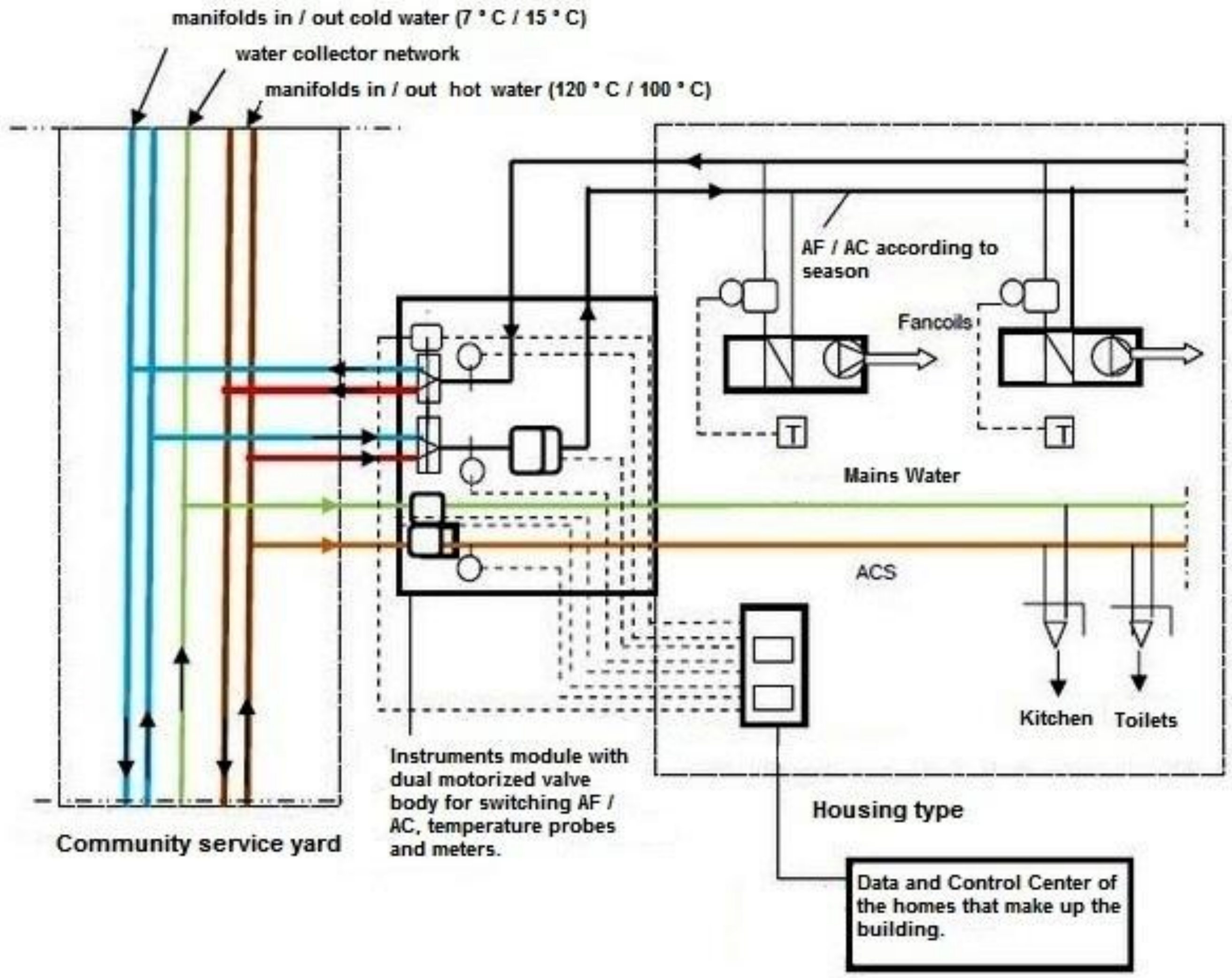
The main motivation for the use of biomass in industry and transport, is the emission of CO_2 into the air caused by burning fossil fuels, with global consequences. The availability of land, improved technologies to raise yields and improve the efficiency of its use, are gaining and opening a huge new market. The amount of money representing the market can be greater than the one today represented by agriculture. Developing countries, especially tropical ones, can take advantage of this fact to increase their profits and a better quality of life for its population.

Now it is time to strengthen this energy source, showing applications of the technology currently available. Because it is, a renewable energy available to almost all parts of the world. Because the planet sustainability depends on the sustainable use of the Earth natural resources. The Earth resources can provide or more clearly, should provide, the energy of which we all are dependents.

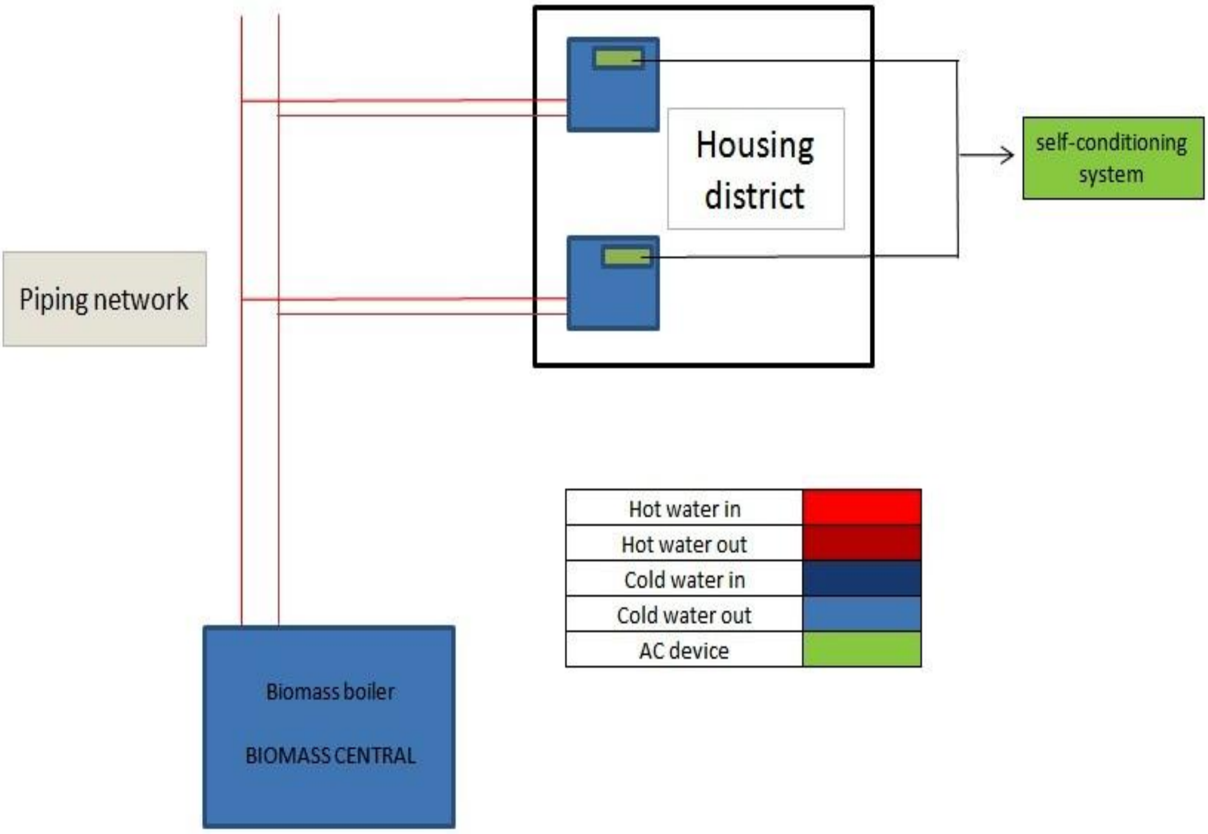
ANNEX I

A- Conceptual Designs

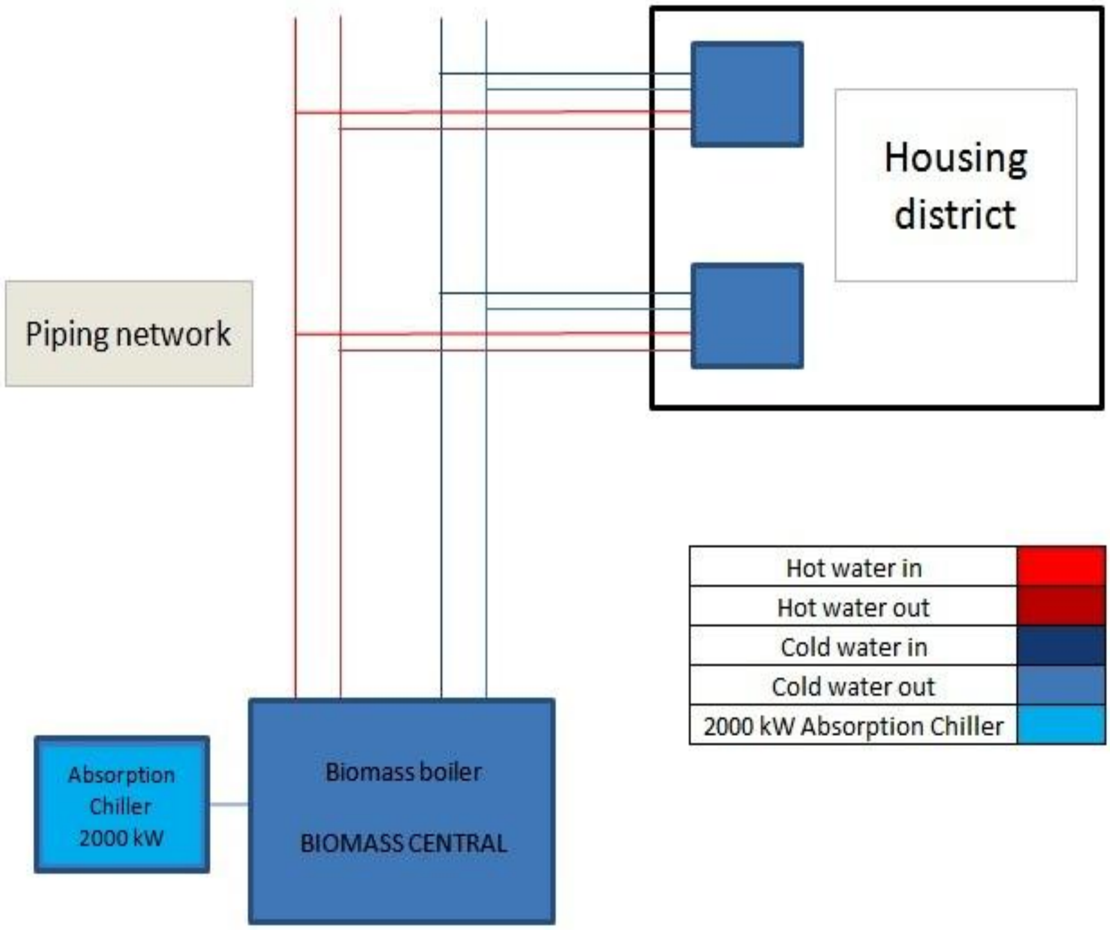
- **Main Design**



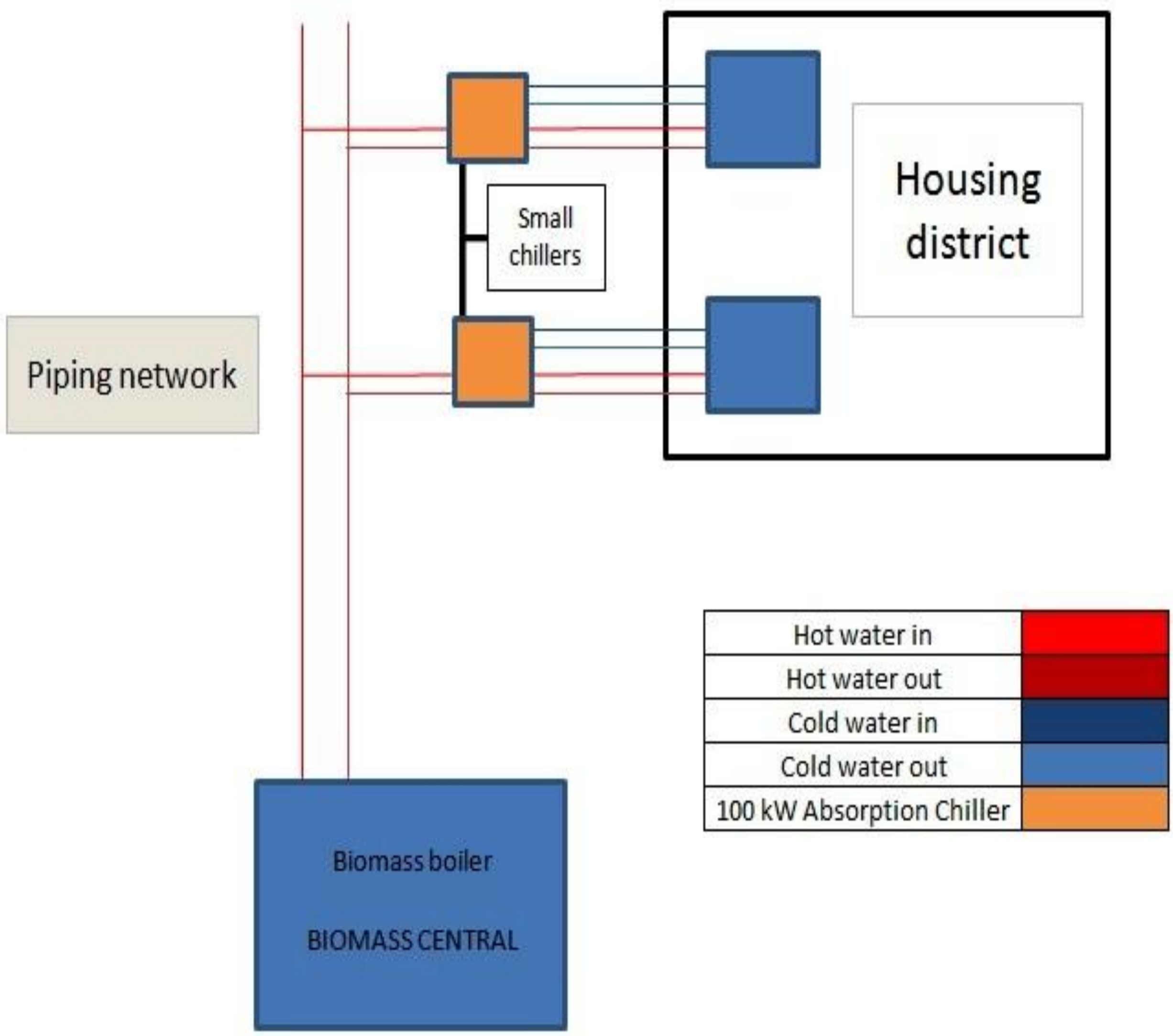
- **Heating + self-conditioning system (*Original system)**



- **Heating and cooling provided by District Heating and Cooling (Absorption chiller ≥ 2000 KW)** ***(*Main thesis design)***



- **Heating and cooling provided by District Heating and Cooling (Small chillers ≤ 100 KW)**



- **Schematic of a basic vapour compression refrigeration system**

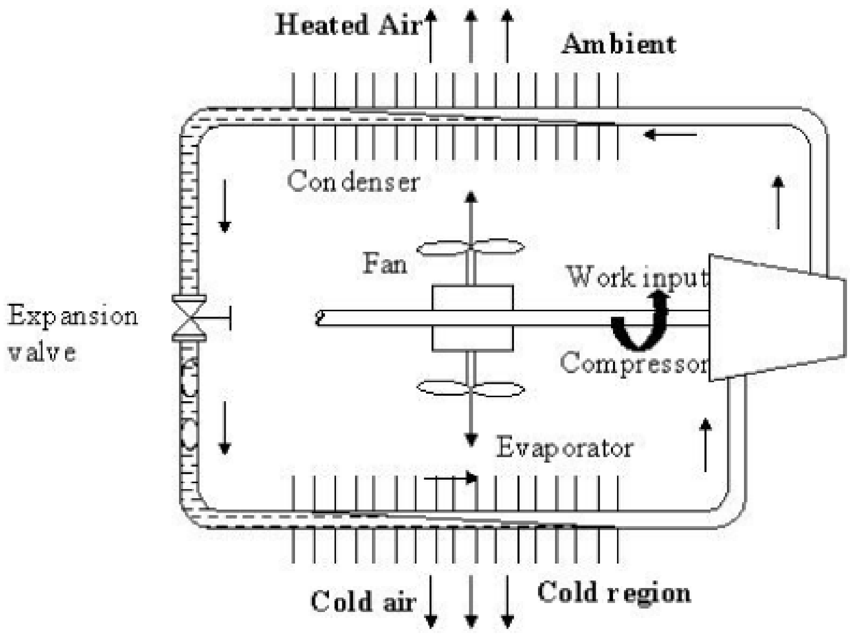


FIGURE 45. Vapour compression refrigeration system. Source: History of Refrigeration.

- Essential components of a vapour absorption cooling system

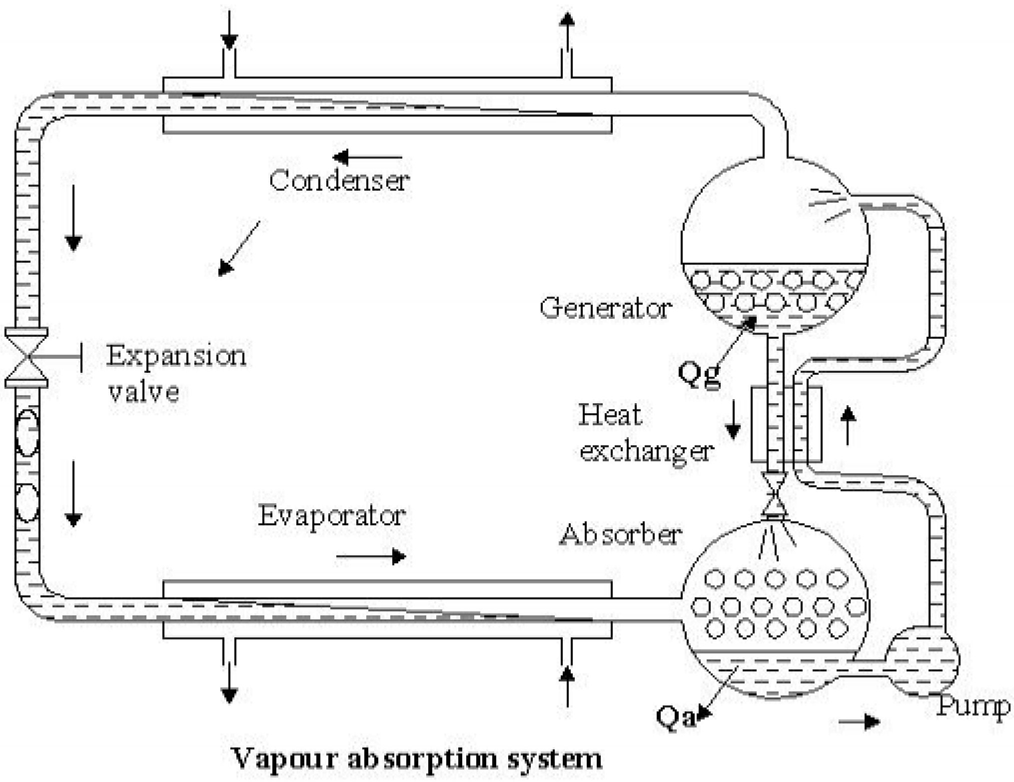
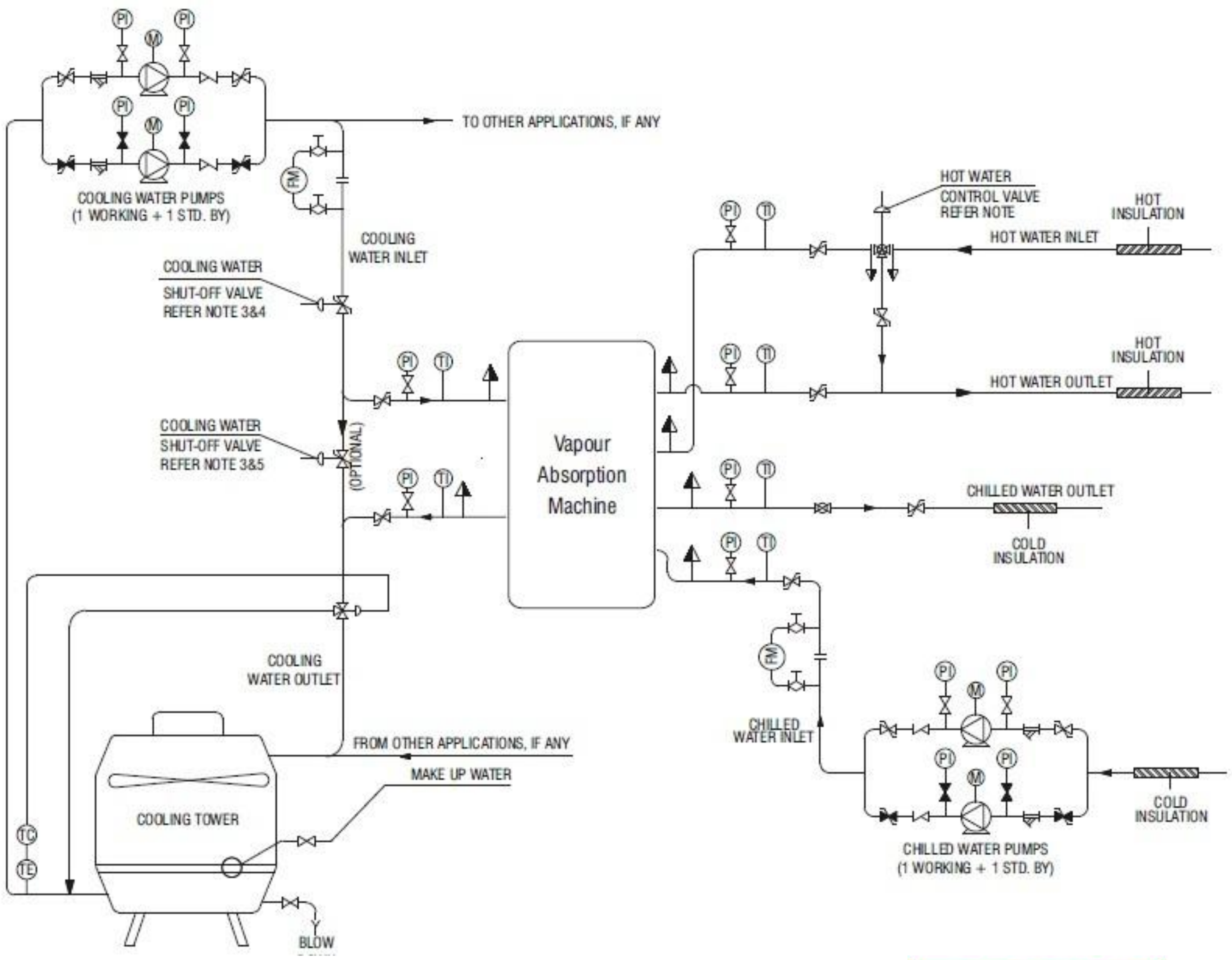


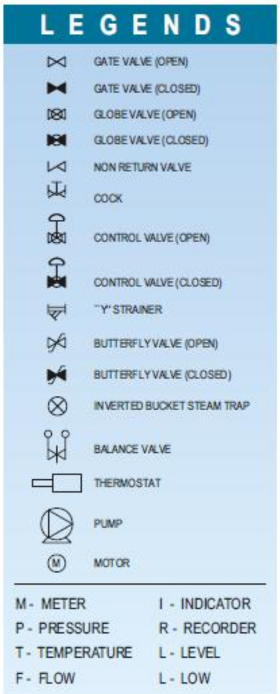
FIGURE 46. Vapour absorption refrigeration system. Source: History of Refrigeration.

- Example of P&I Diagram



Note:

1. Automatic arrangements should be provided to stop cooling water flow in the chilled water flow stops.
2. Thermax scope is up to the nozzles of all water circuits.
3. Pneumatic valve will supplied as standard & electric valve on request.
4. Cooling water shut-off valve to be provided at m/c inlet if cooling water pump is not dedicated to m/c.
5. Cooling water shut-off valve to be provided on m/c by-pass if cooling water pump is dedicated to m/c.



B - Technical specifications sheet

- **Hot water fired absorption chiller – LT-T SERIES provided by THERMAX.**

THERMAX			
HOT WATER FIRED ABSORTION CHILLER - LT - T SERIES			
	MODEL		LT 42T
	DESCRIPTION	**UNIT**	
	CAPACITY (±3 %):	**kW**	2000.0
	COP		0.766
A	**CHILLED WATER CIRCUIT:**		
1.	Chilled water flow	m^3/ hr	214.4
2.	Chilled water inlet temperature	°C	15.0
3.	Chilled water outlet temperature	°C	7.0
4.	Evaporator passes	No.	1 + 1
5.	Chilled water circuit friction loss	kPa	22.5
6.	Chilled water circuit pressure drop	kPa	28.4
7.	Chiller water connection diameter	DN	250.0
8.	Glycol type		NA
9.	Chilled water glycol %	%	0.0
10.	Maximum working pressure	kPa(g)	785.0
B	**COOLING WATER CIRCUIT:**		
1.	Heat rejected	kW	4609.8
2.	Cooling water flow	m^3/ hr	515.0
3.	Cooling water inflet temperature	°C	28.0
4.	Cooling water outlet temperature	°C	35.7
5.	Absorber/Condenser passes	No.	2,2/1+1
6.	Cooling water circuit friction loss	kPa	82.8
7.	Cooling water circuit preassure drop	kPa	95.0
8.	Cooling water connection diameter	DN	300.0
9.	Glycol type		NA
10.	Cooling water gycol %	%	0.0
11.	Maximum working pressure	kPa(g)	785.0
12.	Minimum cooling water intlet temp.	°C	20.0
C	**HOT WATER CIRCUIT:**		
1.	Heat input	kW	2609.8
2.	Hot water flow (± 3 %)	m^3/ hr	118.0
3.	Hot water inlet temperature	°C	120.0
4.	Hot water outlet temperature	°C	100.0
5.	Generator passes	No.	4 + 4

6.	Hot water circuit friction loss	kPa	88.2
7.	Hot water circuit pressure drop	kPa	92.9
8.	Hot water connection diameter	DN	200.0
9.	Glycol type		NA
10.	Hot water glycol %	%	0.0
11.	Maximum working pressure	kPa(g)	785.0
D	**ELECTRICAL DATA:**		
1.	Power supply		415 V ± 10%, 50 Hz ± 5%, 3 Pha-se+N
2.	Power consumption	kVA	11.2
3.	Absorbent pump rating	kW (A)	3.7 (11.0)
4.	Refrigerant pump rating	kW (A)	0.3 (1.4)
5.	Vacuum pump rating	kW (A)	0.75 (1.8)
E	**PHYSICAL DATA:**		
1.	Length	mm	5660.0
2.	Width	mm	2400.0
3.	Height	mm	3520.0
4.	Operating weight	kg	19400.0
5.	Flooded weight	kg	30700.0
6.	Dry weight	kg	13800.0
7.	Shipping weight	kg	16200.0
8.	Tube cleaning space	mm	4000.0
9.	Minimum / Maximum plant room tem-perature	°C	5.0 / 45.0
F	**TUBE METALLURGY:**		
1.	Evaporator		Cu Finned
2.	Absorber		Cu Mini Finned
3.	Condenser		Cu Plain
4.	Generator		CuNi Mini Finned
G	**Fouling Factor:**		
1.	Chilled water fouling factor	m^2 K/kW	-
2.	Cooling water fouling factor	m^2 K/kW	-
3.	Hot water Fouling factor	m.K/kW	VALUE

NOTES:

1. This selection is valid for insulated chiller only.
2. For non-insulated chiller, the capacity & heat source consumption will vary.
3. Please contact Thermax representative / office for customised specifications.

- **Allowable range of standard water quality provided by THERMAX.**

STANDARD WATER QUALITY

Allowable Range for Circulating Water in Chilled water and Cooling water

Items	Units	Cooper
pH (25°)		7.0 - 8.5
TDS	ppm	< 1500
TSS (Turbidity)	ppm	< 10
M Alkalinity	ppm	< 100
Chloride Ion Cl	ppm	< 400
Sulphates Ion SO_4 - (For scaling only)	ppm	< 500
Silica	ppm	< 75
Total Hardness	ppm	< 300
Calcium hardness	ppm	< 200
Total Iron S	ppm	< 0.1
Sulphide Ion S -	ppm	Not detected
Ammonium Ion NH_4 +	ppm	< 1
Biological Oxygen Demand (BOD)	ppm	< 50
Chemical Oxygen Demand (COD)	ppm	< 100
Free Chorine	ppm	< 0.1
Oil & Grease	ppm	< 1
Other contaminations like Phenol, cynide, lead, managanese etc	ppm	Not detected

- Fan coil technical data

ICF015 **Ud** **Ceiling fan coil, four-pipe system, with distribution channels.**

Horizontal fan coil without casing, NCH Major Model 325 "CIAT", set of four tubes, total nominal cooling capacity of 1.51 kW (wet-bulb temperature of inlet air: 19 ° C water inlet temperature: 7 ° C, jump temperature: 5 ° C), nominal heat output of 0.97 kW (air inlet temperature: 20 ° C water inlet temperature: 70 ° C), a valve, "HIDROFIVE. "

Broken down	Ud	Description	Rend.	p.s.	Item price
mt42ftc200fhbl	Ud	Horizontal fan coil without casing, NCH Major Model 325 "CIAT", set of four tubes, total nominal cooling capacity of 1.51 kW (wet-bulb temperature of inlet air: 19 ° C water inlet temperature: 7 ° C, jump temperature: 5 ° C), nominal heat output of 0.97 kW (air inlet temperature: 20 ° C water inlet temperature: 70 ° C), 7-speed 3 are wired from the factory, flow nominal water from 0.302 m³ / h nominal air flow of 230 m³ / h Sound power rating of 48 dBA.	1,000	261,04	261,04
mt42vsi010ahq	Ud	Three-way valve to bypass (4 channels), model ACC88.401/HDF "HIDROFIVE" STA71HDF actuator, including connections and assembly.	1,000	206,00	206,00
mt42vsi010ahq	Ud	Three-way valve to bypass (4 channels), model ACC88.401/HDF "HIDROFIVE" STA71HDF actuator, including connections and assembly.	1,000	206,00	206,00
mt37sve010b	Ud	Brass ball valve plated rings for 1 / 2 ".	2,000	4,13	8,26
mt37sve010b	Ud	Brass ball valve plated rings for 1 / 2 ".	2,000	4,13	8,26
mo003	h	1 st official installer of air conditioning.	3,116	23,78	74,10
mo054	h	HVAC Installer Assistant.	3,116	20,41	63,60
	%	Aids	2,000	827,26	16,55
	%	Indirect costs	3,000	843,81	25,31
Ten-year maintenance cost: € 243.35 in the first 10 years.				Total:	869,12

ANNEX II

✓ Energy Efficiency: Doing More With Less in the European Heating and Cooling Markets

Speaker: Professor Sven Werner

Chalmers University (Sweden)

In recent resolutions and reports, the European Parliament stresses the importance of developing an energy system which allows Europe to meet its climate objectives, to reduce its dependence on imports and to ensure long-term competitiveness in line with the Lisbon agenda. A more responsible use of fossil fuels, along with the promotion of renewables, are recognised as key instruments.

Heating and cooling of buildings accounts for roughly 40% of all energy use in the EU. In that context, how can the heating and cooling sector contribute to achieving the objectives?

Prof. Sven Werner has extensive experience in research, consulting and management in the energy industry and is one of the main authors of the Ecoheatcool study. This study, which is co-funded by the European Commission, aims at providing insight in the European heating/cooling markets, identifying possibilities for more district heating/cooling and issuing strategic recommendations to decision-makers. In his presentation, Prof. Werner outlined first results of the work.

Source: EUROPEAN ENERGY FORUM http://www.europeanenergyforum.eu/archives/european-energy-forum/energy-management-and-policy/energy-efficiency-doing-more-with-less-in-the-european-heating-and-cooling-markets

✓ What is AVEBIOM?

AVEBIOM was established in Valladolid on May 11, 2004 to promote the development of bioenergy sector in our country.

Priority objectives:

• Promote the creation and development of the bioenergy sector in Spain.
• Involve the government with powers such as Agriculture, Environment, Industry and Economics.
• Promote the creation of packaging companies, marketing and supply of solid biofuels as well as those working in energy recovery, the production

of biofuels and biogas, as well as the equipment necessary for their production, transport and recovery.

AVEBIOM is open to all who can contribute or demanding something to help the development of biomass for energy purposes: farmers, foresters, businesses of primary and secondary processing of agricultural and forestry products, developers, electric generators, process industries, communities , Individuals, technologists, equipment manufacturers, manufacturers of boilers and combustion equipment and handling equipment manufacturers to harvest, handling, transport and processing, universities, research institutes, financiers and lawyers, young consumers,.

Source: (http://www.avebiom.org/pub_ave_tex.php)

✓ Letter from the Publisher

Energy cooperation and stability in the Mediterranean region

The difficulties of implementing the fledgling “Union for the Mediterranean” have just been underlined by the resignation of the institution’s Secretary General, the Jordanian Ahmad Maddad’eh. These difficulties are known to be due partly to the tensions created in the Middle East by the Israeli-Palestinian conflict. They also originate in blocking moves among European states that do not all see the institution in the same light, while the obstacles standing the way of rapprochement in the Maghreb are not without their own impact.

The gradual political destabilization of the southern Mediterranean states is further modifying the situation. If we look back to the end of the European “Eastern bloc” in 1989 which led to the re-creation of a series of stable, democratic states, the current situation on the southern shore of the Mediterranean may well be sorted out in the not-too-distant future.

Be that as it may, there will be no decline in the current profusion of large-scale energy projects in the region for the time being.

A number of projects are competing with one another and with projects – which are themselves redundant – to carry natural gas to the northern shore of the Mediterranean from the Caspian Sea. Eventually an overall view will be needed. The Union for the Mediterranean – one of whose identified objectives is energy – should provide an appropriate setting for the consultation required.

Energy cooperation around the Mediterranean is set to intensify, upheld by the development aspirations of numerous peoples that will render stability in the region a necessity.

From this point of view, the European Union will play a vital role and the impetus provided by the European Commission will consequently prove decisive. The specific function of energy in all its various aspects, from production to transport, inevitably entails the specific responsibility of the “impulse provider”. The appointment of Commissioner Günther Oettinger to head international relations in the field of energy augurs very well.

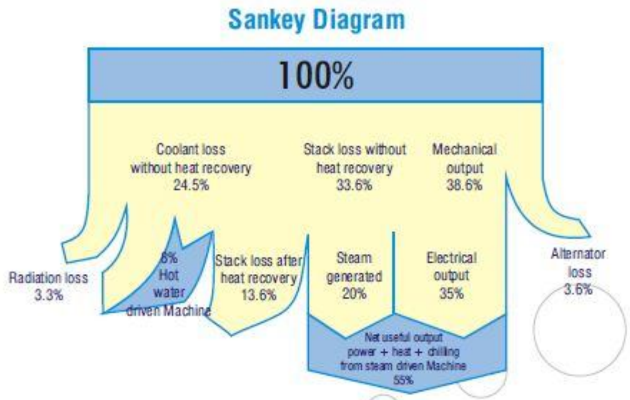
The project planned as described in the editorial of March 2009 – two years ago now – seems increasingly advisable. Intended to provide information for large numbers of national and local members of parliament faced with industrialists and highly qualified officials, it was to give the elected representatives of the various countries around the Mediterranean the opportunity to find out more about and assess in greater detail the energy situation in the region, as well as the possibilities offered by energy for appropriate social economic and social development.

Source: http://www.europeanenergyforum.eu/archives/european-energy-forum/letters-from-the-publisher/energy-cooperation-and-stability-in-the-mediterranean-region

✓ Combined Heat, Power & Cooling System

The following information is showed in the catalogue of THERMAX. It is the explanation of coogeneation together with several intuitive graphics. It also shows aswell the main principles that take part in the process. Litium Bromide is the fluid that uses the absorption chillers that this thesis aims to study as solution proposals.

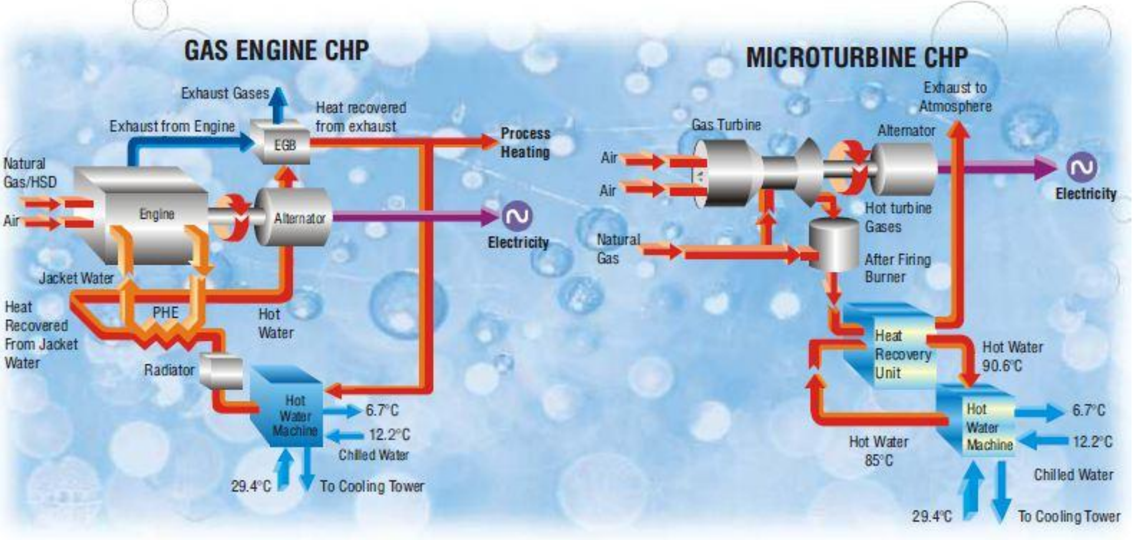
The concept of co-generation by means of Genset (engine) based CHPC is becoming increasingly popular worldwide for reducing overall energy costs.



Sankey Diagram:

The Sankey Diagram shows the heat energy distribution per unit quantity of fuel to a Genset. The portion indicated in blue represents the net useful output which is raised from 35% to 65% by recovering the waste heat from exhaust gases and jacket water, to enhance the utilization of fuel.

Around 25% of the input energy of the Genset is wasted in a cooling tower to cool the jacket water coming out of the engine, which is at a high temperature. The same heat can be used as an energy heat source for the Hot water driven machine to produce chilling at a negligible cost. The typical system schematic given below explains the connectivity between the Genset and the Hot water driven Vapor absorption machine.



Basic Principle:

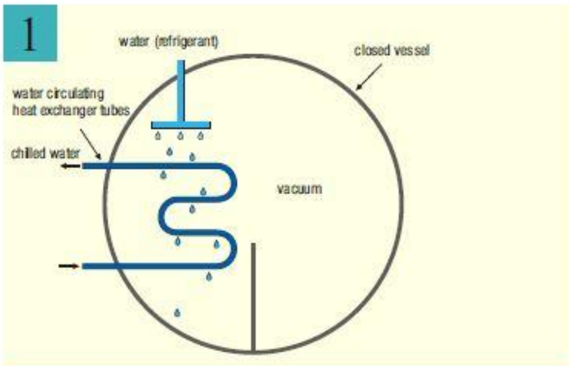
Boiling point of water is a function of pressure. At atmospheric pressure, water boils at 100°C. At lower pressure it boils at lower temperature. The boiling point of water at 6 mm of Mercury absolute, is only 3.9°C.

Lithium Bromide (LiBr) salt has the property to absorb water due to its chemical affinity. It is soluble in water. As the concentration of LiBr increases its affinity towards water increases. Also, the Temperature of LiBr this affinity decreases.

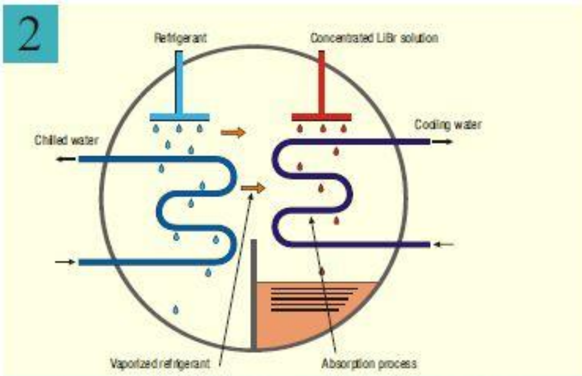
There is a large difference between Vapor pressure of LiBr and water.

Operating Principle:

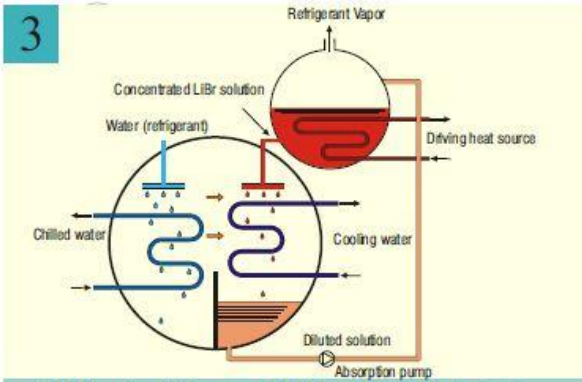
The Vapor absorption machine produces chilled water upto 4.4°C, utilizing hot water as the driving source. The machine utilizes the latent heat released by the refrigerant (water) as it evaporates (in a closed pressure vessel) for cooling. Unlike a compression machine which uses a compressor to pressurize the Vaporized refrigerant (Freon) and condenses it by using cooling water, the absorption machine uses an absorbent (LiBr) to absorb the Vaporized refrigerant (water). The refrigerant is then released from the absorbent when heated by an external source.



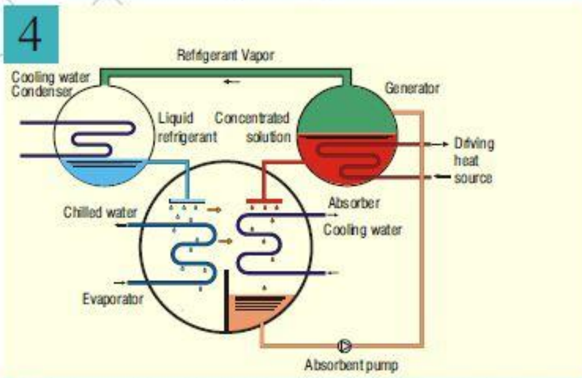
When maintained at high vacuum, water will boil and flash cool itself.



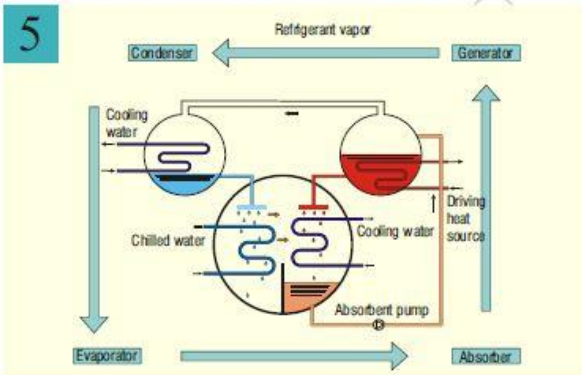
Concentrated Lithium Bromide solution has affinity towards water. The solution absorbs Vaporized refrigerant water.



As Lithium Bromide becomes dilute it loses its capacity to absorb water Vapor. It thus needs to be reconcentrated using a heat source.



This heat causes the solution to release the absorbed refrigerant in the form of vapour. This vapor is cooled in a separate chamber to become liquid refrigerant.



The basic operation cycle of the single effect Vapor absorption machine.

✓ Principle and historical background of absorption refrigeration cycle.

The thermodynamic cycle absorption cooling, as well as compression, is based on the need of the fluid used as coolant for heat the liquid to cool to pass from liquid to vapor at reduced pressure he is under . In refrigeration, the fluid is a liquid at higher pressure in the condenser and is made to flow to the evaporator at low pressure where the environment comes from the heat required to evaporate. This refrigerant is in vapor high pressure is returned to the condenser where it is subtracted the heat that has won back to a liquid to start the cycle again. This achieves the aim of taking heat from a space, the evaporator, cooling to dissipate in another, the capacitor.

While in the compression cycle, the fluid flow and pressure effect is obtained with a mechanical compressor in the absorption cycle this is achieved by providing heat to the generator where the refrigerant is mixed with another fluid whose function is called absorbing absorb the vapor in the area of low pressure in liquid form can be returned to the generator.

The absorption cycle is not a recent discovery. Its history can be in 1755, when the Scotsman William Cullen managed to obtain a small amount of ice in a hood where he maintained a reduced pressure. Soon after, in 1777, another Scot, Gerald Nairne, sulfuric acid introduced into the hood of Cullen, so that water vapor was absorbed by it, leaving room to allow for greater water evaporation. Somewhat later, in 1810, John Leslie placed inside the vacuum bell, a container of water to evaporate and bottom beakers with sulfuric acid, with a production of 3 kg of ice per hour.

But the French finally Ferdinand Carré, who builds and sells the first m achine of absorption, mainly for the manufacture of ice, using ammonia as refrigerant and water as absorbent. This machine was patented in 1859 and won the Universal Exhibition in London in 1862. Paraguay In 1875 the ship, equipped with machines Carré, transported first frozen meat from Buenos Aires to the port of Le Havre. Until the sixties of last century, this technique was developed especially in the United States, however, has evolved particularly in Japan, probably due to the energy policy for this country. Versions of flame where the heat is supplied by a fuel burner or other hot water, which uses the energy contained in hot water from solar, cogeneration equipment or other sources of free or residual heat.

The development of this technology has resulted in two major groups based on the refrigerant and the type of absorber used. One uses a solution of ammonia and ammonia water being the refrigerant and water absorbent. In this family under the signature teams ABSORSISTEM ROBUR distributed. The other group used a solution of lithium bromide (LiBr) in water where it acts as a refrigerant being salts LiBr absorber. Brand teams and THERMAX YAZAKI distributed ABSORSISTEM also belong to this second family.

✓ The short-term cooling but long-term global warming due to biomass Burning

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(Submitted for publication, August 30, 2002; Revised February 5, 2003)

- ABSTRACT:

Biomass burning releases both gases (e.g.,CO2, CO, CH4, NOx, SO2, C2H6, C2H4, C3H8, C3H6) and aerosol-particle components (e.g., black carbon, organic matter, K+, Na+, Ca2+, Mg2+, NH4+, H+, Cl-, H2SO4, SO4-, SO42-, NO3-). To date, the global-scale climate response of controlling emissions of these gas plus particle constituents during biomass burning has not been examined. Whereas biomass-burning particles enhance global cooling in the short term, it is estimated that this cooling may be more than offset after 40-60 years by the warming effect of long-lived biomass-burning gases. The emission of the most important of these gases, CO2, is only partially offset by biomass regrowth each year. It is proven with an analytical solution here that, for any time lag between biomass burning and regrowth, burning causes a net accumulation of CO2 in the atmosphere, even when burning and regrowth fluxes are equal. It is further shown that, when grassland or cropland is burned yearly, as opposed to being burned every 25 years, there is an accumulation of atmospheric CO2. The implication is that biofuel burning, considered a “renewable” energy source, is only partially renewable, and biomass burning always produces elevated CO2 until it is stopped. Because CO2 from biomass burning has been considered recyclable and biomass particles are thought to cool climate, the Kyoto Protocol did not consider control of biomass burning. If the results here, which are2
subject to uncertainties, are correct, such control may slow global warming, contrary to
common perception. Control will also improve human health.burning. If the results here, which are subject to uncertainties, are correct, such control may slow global warming, contrary to common perception. Control will also improve human health

Source: http://www.stanford.edu/group/efmh/bioburn/Respbiob.pdf

ANNEX III

Diary of the Project

Background

The starting point of this Project is my interest, mixed in with the collaboration of Miss Anneli Kakko who made possible that opportunity. March of 2010, I was in Jyväskylä for the first time doing the Intensive Program called "User Friendly Design and Innovations for Senior Citizens", managed by JAMK During the last days of that course I showed my interest to do my final thesis at JAMK.

*Link with the IP report:
(http://www.jamk.fi/download/25211_Learning_Diary_-_Team_3.pdf).

After being in touch with Miss Anneli Kakko during the summer, we reached to an agreement between the two universities. Finally I realized that the thesis turned out to be possible. On August 2010 I was coming back to Jyväskylä.

My main idea was to write a thesis about renewable energies, regardless of field. Then, I was interviewed by Miss Varpu Savolainen, JAMK Bioenergy Development Centre. She was the contact person between me and a company. As a result, the company BENET Oy looked to be interested in someone from Catalonia for studing the feasibility of biomass projects in that area.

Finally the 8th of September I met for the first time with Mr. Asko Ojaniemi, Managing director of BENET Oy.

BENET bioenergiaverkosto

UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA

JYVÄSKYLÄN AMMATTIKORKEAKOULU
JYVÄSKYLÄ UNIVERSITY OF APPLIED SCIENCES

The start with the company

During my first meeting with the company, we spoke about the renewable energies and the Catalonian situation in the field of energy. I started to realize the big amount of knowledge of Finnish companies about the biomass field. I saw a big opportunity for learning and wining experience in that field.
After a few meetings, Mr. Asko Ojaniemi spoke to me about his interest in the cooling systems with biomass, thinking about Catalonia and their weather. So finally, we concluded to study the feasibility, economically and technically, of adding a cooling system in one of the existing biomass plants in Catalonia. As a result of that came the title of the thesis:

"FEASIBILITY STUDY OF COMBINED HEATING AND COOLING BY BIOMASS"

The tutoring from JAMK

On 16th of September 2010 I signed the bachelor's thesis topic proposal. Accepted by Dr. Juhani Alakangas, Senior Lecturer. After that, Dr. Jaakko Fonselius, Dr. Tech., Principal lecturer in Machine Automation Mechanical Engineering was chosen to be responsible for the thesis tutoring.

The project process

During the first months, I studied the topic of the biomass in Catalonia. Also, I have been studying the plant process, first with heating, and then with cooling as well. All that time, I had meetings with Mr. Asko Ojaniemi, explaining him the project ideas, asking him about my doubts. Trying to realize myself, exactly, what was his idea of the project? He explained to me about some news, about his contacts in Catalonia. They seemed to be very interested.

For me, it was very motivating, the idea that we could find a biomass plant for used as a real case in my thesis. At the same time, the thesis has taking longer than I expected, but in a very interesting and useful way for me. Then, in December of 2010, during my Christmas break in Barcelona, I had the opportunity to meet, personally, Mr. Xavier Solanes, engineer at ICAEN. He is working in the General Directorate of Natural Environment and Biodiversity for the Catalan government.

The first meeting with ICAEN

In the meeting with Mr. Xavier Solanes we spoke about the possibilities which he could offer me, in order to find a real case to study. He was encouraging me with some ideas to solve the matter. The first case was about a fruit company called NUFRI, located in Mollerussa, Catalonia. They have a co-generation biomass system and we thought about it. It seemed that they needed cooling for the fruit store, so it turned out interesting to introduce cooling, with biomass too. During the first week of January, they answered that they were not interested to do the study, and I had to come back to Jyväskylä.

Once back, I met again with Mr. Asko Ojaniemi . He spoke about the possibility to contact Mr. Ignacio Lopez. He is working in the department of Forest, Harvesting and Biomass, for the Forest Technology Center of Catalonia. I got in touch with him via email and he answered me and was very interested. He spoke about the possibility to study the biomass plant located in Molins de Rei.

Finally, Mr. Xavier Solanes emailed me saying that he had found a biomass plant interested in my thesis. The biomass plant of Molins de Rei, one of the firsts districts heating with biomass which became operational in Catalonia.

First contact with Molins Energy Company, Ltd.

In the email of Mr. Xavier Solanes I had the information of the contacts for geting in touch with the biomass plant managers. Let me explain that, Molins Energy Company, Ltd. is a company formed by four partners, three of them are from the public sector, and one of them, the largest investor, is from the private sector. In the first week of February, I called to Mr. Joan Arús, the section chief of sustainability. I spoke with a responsible of the department and he said to me that the four partners need to have a meeting, to speak about and then decide. He also assured me about the interest that they have. Finally, the responsible of the biomass plant chose to stay out of the thesis.

The end

It is then when I had to start to work with the information which I was collecting. All the data from the biomass plant of Molins de Rei comes from the internet. The technical parts of the thesis are the result of several meetings with the company BENET.

Symbolic

E =VOLTS or (V = VOLTS)
P =WATTS or (W = WATTS)
R = OHMS or (R = RESISTANCE)
I =AMPERES or (A = AMPERES)
HP = HORSEPOWERPF = POWER FACTOR
kW = KILOWATTS
kWh = KILOWATT HOUR
VA = VOLT-AMPERES
kVA = KILOVOLT-AMPERES
C = CAPACITANCE
EFF = EFFICIENCY (expressed as a decimal)
MW – MEGAWATTS
ktoe = KILOTONNES OF OIL EQUIVALENT

FIGURES

TABLES

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