UNIVERSITA' DEGLI STUDI DI PADOVA

Dipartimento di Ingegneria Industriale DII

Corso di Laurea Magistrale in Ingegneria Meccanica

Investigation of district heating systems with renewable energy sources in Italian conditions

Relatore: Michele De Carli

Correlatore: Artur Rogoza

Studente: Matteo Lavagnini

Matricola: 1056201

Anno Accademico 2014/2015

Riassunto

In questo lavoro si è attuata dapprima un'indagine preliminare sulla situazione energetica italiana studiando le problematiche relative al consumo di gas naturale passando poi ad una valutazione generale sulle possibili biomasse presenti sul territorio derivanti principalmente da scarti o da sottoprodotti industriali. In seguito è stata eseguita un analisi sui sistemi di teleriscaldamento presenti in Italia e sulle diverse metodologie di produzione del calore passando dalla cogenerazione alle biomasse. Partendo da quest' ultima tipologia si è studiato un possibile impianto alimentato a paglia, un prodotto di scarto dell'agricoltura spesso non utilizzato e lasciato sul terreno, ma le cui caratteristiche energetiche non sono inferiori a quelle del cippato, il quale rappresenta il combustibile maggiormente utilizzato nei piccoli impianti di teleriscaldamento montano. Situato nella periferia della città di Verona ed allacciato a 42 edifici con una superficie totale di 39.000 m^2 l'impianto si troverebbe in una zona con buone quantità di biomassa, maggiore rispetto alla reale necessità dell'impianto. Dopo aver stimato il consumo energetico degli edifici della zona è stato dimensionato il sistema di distribuzione e la centrale termica con la caldaia a paglia e relativo sistema di alimentazione studiato ad hoc per questa biomassa, affiancata poi da due caldaie a metano. Sono stati valutati i consumi annuali e mensili di paglia e con quest'ultimi si è dimensionata la zona di stoccaggio presso la centrale termica.

In parallelo si sono sviluppati due sistemi alternativi studiati su due diversi edifici per dimensioni e consumi rappresentativi del quartiere. Questi sistemi, che sfruttano anch'essi le energie rinnovabili,sono costituiti: il primo da una con pompa di calore affiancata da una caldaia a gas mentre il secondo da una caldaia a condensazione affiancata da dei collettori solari per la produzione di ACS. I tre sistemi studiati sono stati confrontati tra di loro prendendo a riferimento la situazione esistente costituita da singole caldaie a metano. Dopo aver considerato tutti gli incentivi governativi presenti: certificati bianchi, crediti di imposte e Conto Termico, si è effettuato un confronto considerando i diversi costi di installazione, gestione e produzione del

calore. Un ulteriore confronto è eseguito considerando l’aspetto ambientale e le amissioni di CO_2 dei diversi sistemi.

Abstract

In this work has been realised a preliminary study on the Italian energy situation analysing the consumption of natural gas and after making a valuation of the different kind of biomasses present in the territory derived principally from waste and industrial by-products. Next is investigated the situation of Italian district heating and the different methods for the production of heat: starting from cogeneration to biomass system. Studying in depth this last sector is evaluated the possibility to realise a plant feeds with straw, an agriculture by-product usually does not use and leaves on the ground but which energetic characteristics are not less performance then chips, the main fuels for the small plant of DH present in the mountain area. The plant that you want to study will be place in the suburb of Verona, in an area with 42 buildings with an overall surface of 39.000 m^2. The plant will be surrounded from a great quantity of straw presents in the area of Verona, more than the quantity strictly necessary for the functioning. The energy consumption for the buildings present in the area is evaluated and after is designed the grid and the boiler house with the straw boiler and the relatively feeding system plus two natural gas boilers. Yearly and monthly consumption of straw are calculated and with the last, the straw storage is dimensioned.

In parallel with DH are evaluated two alternative solutions for two buildings representative of the entire group. These systems exploit renewable energy and are composed by: the first with heat pump and gas boiler and the second with condensing boiler and solar collectors for the DHW production. The three systems are compared took a reference the existing situation represents from private boiler feed with natural gas. All incentives give from the government are evaluated and are: white certificates, tax rebate and other give from "Conto Termico". The comparison is made considering the different cost of installation, management and price for the production of heat. Another comparison is made considering the environmental effect analysing the reduction of CO2 emission.

Summary

Introduction

Imagine a scenario for the developmental of renewable energy is made difficult for the presence of many factors and variables that stimulate or reduce their diffusion. A fundamental rule is due to the government incentives, the price of fossil fuels that is continually changing, and the volition of the people to use renewable energy. In the same way is not easy to predict the production of CO_2 in the word. Critical will be the rule of developing country, because the consumptions of energy is closely related to the level of reach. The habitants of these countries are about the half of the global population and probably their level of reach will be similar to the westerns countries in the next 50 years. If these lands will adopt a lifestyle similar to ours, the battle for the reduction of CO_2 will be lose. To avoid a quickly variation of the clime, in the next 50 years, the emission per capita will must be reduced of 2.3 tons or rather decrease more than 50%. The International Energy Agency (IEA) aim to fix the CO_2 in the atmosphere in 450 ppm, like the maximal sustainable value, against the 380-ppm in the 2006 and the value of 280ppm presents 300 years ago. According to IEA, this target won't be reached only with the use of renewable energy but will be necessary to focalise on the energy efficient. Moreover, other system should be used as the capture of CO_2 or the utilization of nuclear energy.

UE, in relationship to the other geopolitical area in the word, is leader in the battle for the reduction of CO_2 and contrasting the change of the clime. The final goal of all the politics is decrease quickly the CO_2 emission and confine the increasing of global warming in a value that can not be so dangerous for the word. The main instruments that the UE use are included in a pack of laws call: "UE climate and energy package" approved in December 2008. The package indicates the year 2020 as a fundamental point for the reduction of CO_2 emission thinking to a more sustainable society. In the same time, the adopted measures have the purpose to increase the economic and create new jobs in Europe. Moreover, UE wants to reduce its dependences to the petrol and natural gas importations. The estimates announce a yearly saving of about 50 billion of Euro on the bill for the energy importation and 1 million of new jobs. The packed includes a new commitment that can summarized in this point

1) An average reduction of CO_2 production of 20% in relationship to the values emitted in 1990. The Kyoto protocol already imposed a reduction of 8% before 2012. UE is moreover available in a reduction of 10% more if other country would accepted the same conditions.
2) Increase the use of renewable energy to cover the 20% of the entire production of energy
3) A reduction of 20% of consumptions predict for the 2020 with a more energy efficiently.

To reach the aim the package include a lot of measure that are included in four regulations that has been accepted by our government.

1. Energy situation in Italy

According with the data, provide by the Ministry of Economic Development in Italy in 2013 the primary energy consumption was about 171 million of TOE (ton of oil equivalent) with a drop of 3% compared to the previous year. This value confirms the negative tend caused by the economic crisis. The maximum value has been registered in 2005 with 186 million of TOE. Civil sector is the most import and utilises 27% of the entire amount. Industry is the sector that in the last years has reduced the consumption more.

In relations to the other European country, Italy has a relatively low consumption of primary energy. The per capita value is 2.4 TOE versus a European average of 2.7 TOE and in the year 2010, Italy used only 1.4% of the total used in the word and UE area was used about 14% against the 23% in North America.

Natural gas and renewable energy are the energy source in which Italian government invests more money to create solid basis for the future energy supply. An important issue is the really availability of this resource and how Italy could be independent to the other country. In the next pages will be described the supplying of natural gas and the possibility for the biomass sectors.

1.1 Natural gas

The Italian gross consumption of natural gas was 74,9 Gm^3 in 2012 with a little reduction respect the previous year quantifiable in 3 Gm^3. The consumption in 2012 represents the minimum value in the last years confirming the downward trend. This reduction is due only a few sector as industrial production, agriculture and electric production while, in other field, the demand is instead increase as in civil sector, automotive and other, for not energy used. The reduction in the industrial production is due in particular way to the economic crisis of the last years. Only a small part of this consumption is covered by the internal production, which in 2012 has reached the value of 8.6 G m^3 or rather about 9% respect the entire gross consumption. Net imports have been about 67.6 Gm^3 and 1.3 Gm^3 has increased the national reserve. Merchant of natural gas is complex, and after the liberalisation append the 1 January 2003 there are over 150 company that sale natural gas in Italy.

The major company are ENI, Edison and Gdf Suez. A part of the gas has been used directly by the company for the production of electrictricity and the remaining is sold through the national network. Domestic consumption follow from industry sector represent the main users of natural gas.

Table 1: Different uses of natural gas

Use	Value [Gm^3]
Self- consumption	12.6
Domestic	19.4
Trade and service	6.2
Industry	18.8
Public servant	1.1
Power generation	16.9

The department of mineral and energy resource of the ministry of Economic Development estimates proved reserves of gas at December 31, 2012 in 54,9 Gm^3. Continuing with this rhythm of extraction the reserve will be finished in only seven years. Probably, a little increment of this value is possible considering the probable reserves that need new investments.

Gas imports represents a vital element in the energy plan, 89% of the gas arrives in Italy through pipeline and half of this amount enter from the north part of the country. The most important line enters from Tarvisio where there is the pipeline TAG come from Russia and direct to Austria. Second, there is the pipeline TTCC, direct to Mazzara Del Vallo, which transports the gas from Alger through the Tunisia and represents 30% of the importations. The 13.3% enters in Italy from Switzerland coming from north Europe with the pipeline TENP that across Germany. About 10% comes from Libya with Green Stream and arrives in the city of Gela and another 9% from Qatar to Cavarzene.

The analysis of the contract show as the long-term contract are the most important and covers 65% of the importations and they are long more than 20 years and about a lot to them will expire in more than 15 years.

About the importation, a new European regulation has been introduced in 2013 and it speaks about the new infrastructure for energy. In this document have been introduced four new priority corridor to realize in the next years within the 2020 and three of the four corridor is crossing Italy.

1.2 Exploitation of new biomasses

In Italy, the fossil fuel resources are very limited, over 80% of them are imports like the natural gas. In this scenario, bioenergy are able to contribute to the global demand of energy and they may be used in different way: in solid form, liquid or gas.

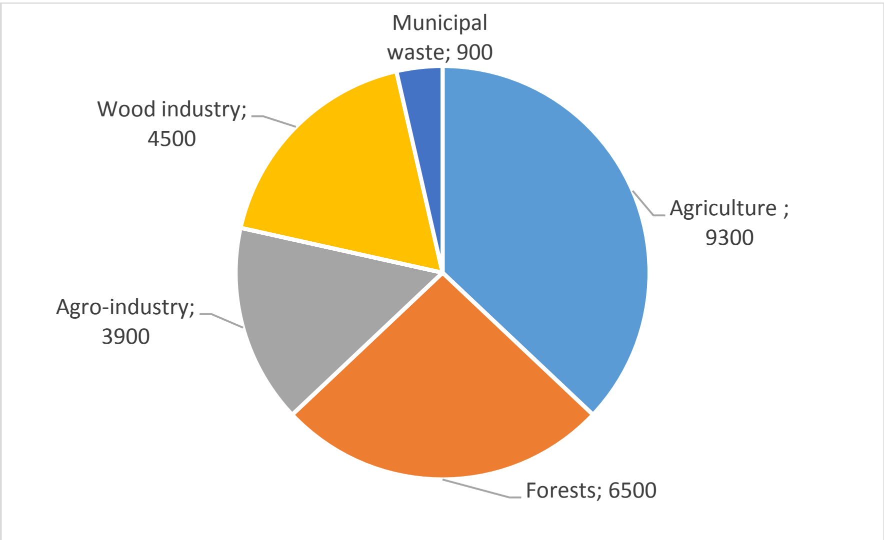
Biomasses represent the main renewable energy for the heat production for which purpose is used over the 92% of the biomass matter. The production of heat marks every year an increment of 3% due in some case to the high price of natural gas or the other traditional fuels.

In the last years, a lot of public and private company have made studies about the possibility to use and the real availability of biomass and the exploitation of different resource like residues from farm, forest and firewood, as well as the biodegradable fraction of municipal or industrial waste. The total amount of residues and by-products of organic nature produced every year in Italy amounts to several tens of millions of tons. However, currently we are able to use only a part of them due to:

- Competition with other non-energy use of bioenergy matter.
- Problems associated with the collection of those materials and the subsequent transfer of energy conversion plant.

A detailed estimate on the real amount is make difficult for the presence of very high number of variables. Considering only the easier resource to use Itabia estimates the presence of 25milion of tons of dry matter derivate from plants and vegetables

Graphic 1: Division of residual biomass [Kton/year]



Over the presence of these residues, the biomass sector can exploit other product or by-product like: livestock waste, wood and energy crops. The amount off all these resource is report in the follow table where are indicate in terms of TOE and their completely exploit can give until 30,6 TOE/year.

Table 2: Amount of biomass in MTOE

Type	MTOE/year
Residual	9,6
Livestock waste	10-12
Wood	2-4
Energy crops (potential)	3-5

1.5.1 Agricultural residues

Agricultural residues consider all the agricultural waste (straw, stems, pruning, etc.) derived from the cultivation of herbaceous plants and trees on the national territory. These residues are always used inside the farm for many different aims (bedding for the cows) and the total available amount is about 9,3 Mtons/year.

Table 3: Agricultural residues

Plant	Typology	Quantity [Kton/year]
Wheat	Straw	2100
Barley	Straw	380
Oats	Straw	120
Rice	Straw	550
Corn	Stalks	3100
Tobacco	Stems	10
Sunflower	Stems	350
Vineyard	Branches	880
Olive tree	Branches	800
Apple tree	Branches	90
Peach	Branches	150
Pear tree	Branches	50
Citrus	Branches	480
Almond tree	Branches	95
Hazelnut	Branches	85
Other	Branches	60

1.5.2 Forest Biomass

New biomass may come making better use of forest. That is possible to exploit better the copse forest (plants that grow again when they are cut) extending the area cover by them from 2% to 5%. Moreover is possible to exploit these trees and their branches. Now the utilization of the tree is about 60% and only this portion becomes wood to burn. Whit the introduction of new machine is possible to extend this value at least 20%. In the last years, are infect developed new machine that mills the branches and makes easier and cheaper the transport due to the reduction of volume. Another source is due to the fine wood, which can be used only for 50% to make board and wooden beams. There are another 30% of matter that can be used to burn. After all these considerations, the available matter for energy purpose is about 13 millions of tons of wet substance or 6.5 millions of tons of dry matter. The current value of wood products to burn in Italy is about 2.2 Mt and then, there is the possibility to increase this value of 2 times but to reach the computed value will be necessary a lot of investments . Currently wood is used mainly from citizen in domestic stove or in commercial activities as restaurant and pizzeria for the wood-baker.

1.5.3 Food- industry By-products

The availability from food and wood industry is significant from the point of view of the energy content. Their use is now partly included in the same production cycle or used in other sector or in other case disposed of. Although these products are used in other sector is better to include its in the calculation. The reason is that the price that they sometimes have in the market is very low and the energy utilization could be more interesting and remunerable. An example of this is in the north-Italy where the demand of chips, changed the normal use in the manufactured of panels, to combustion in boilers. In other cases a matter that didn’t have any commercial value now can be sold about 10-15€/t. In according with ITABIA studies the availably of this material is about 8.4 Mt/year divvied in 3,9 Mt/year from food-industry and 4.5 from wood-industry.

Table 4: Waste from food-industry

Sector	Typology	Quantity [Kton/year]
Sugar factory	sludge, dried beet pulp	1570
Tomato	skins and seeds	135
Citrus	Pulp	210
Fresh fruit	Core	35
Dry fruit	Peel	135
Pasta industry	Broken pieces	60
Rice industry	Husk	520
Oil	Pomace	750
Wine	Pomace	300
Other		185

Table 5: Waste from wood-industry

Sector	Typology	Quantity [Kton/year]
Wood industry	Barks	2500
Wood Industry	chippings	1700
Paper	Pulp paper	300

1.5.4 Municipal Waste

The mass of municipal waste is very strictly connect with the degree of separate collections. Actually, form the separate collection arrives 0.9 Mt/year of wet matter and 0.1 Mt in terms of dry matter. With the maintenance of the green public areas is possible to obtain other 0.38 Mt of dry substance.

1.5.5 Livestock waste

Livestock waste represents a good source of energy and they may be utilized in many different ways as the production of biogas. In Italy are produced every year 300 Mt of livestock waste but only a little part is utilized for the process of digestion. A part of this amount is utilized in the fields for fertilization but not at all the matter can be dispersed in according with the new European rules that establish a precise amount for every hectare. In the country in the north-Europe as German and Netherlands the sewage are valuated about 1.5-5 €/ton. The energy contents calculated in in 10-12 MTEP of primary energy.

1.5.6 New cultivations

New cultivations include the growth of plant for only energetic purpose as sunflowers, rapeseed or poplars. The problem of these cultivations is the directly competition with food plants for the cultivate areas. The cultivation of these plans depends to the economical convenience that normally is not so evident respect food plants. A larger cultivation can bring damage to the food industries and for Itabia the maximum sustainable quantity is calculated in 5 MTEO/years of primary energy divides in biodiesel and wood.

2. District heating

DH is an alternative solution for the production of heat and cold for the climate control of residential or commercial buildings and for industrial activities. The production is made with a centralise system with gas or biomass boiler, exploiting geothermal source or through cogeneration. Heat is distribute using a piping network in which flow a vector liquid like: hot or superheated water and steam. An important factor for these systems is the concentration of utilities that must have a high density to favourite a fast return for the initial high cost.

In Italy, the sector of district heating has been expanding and it is mainly present in north Italy because the clime condition are significantly more rigid and not least in the mountains area there are some place unproved of gas network and making DH more convenient as an alternative to private wood or diesel boiler. In 2011, according with AIRU, there were about 200 networks and at least 90 feed with biomass, excluding municipal waste. The 45% of the entire consumption of primary energy was for heating and cooling of the building and district heating in 2010 has supplied 5% of this demand. Biomass network have usually limited dimensions and are located in mountain but do not miss other big plant present in important city like Torino, Brescia and Mantua that exploit principally cogeneration. The main vector is the hot water with a supplier temperature of (90-85 ° C), only 40 plants use superheated water, and only someone steam. In the last 11 years the average grow of this system has been about 7,5% every year like new m^3 of building cover. The total length of the pipeline in 2011 was 2952 Km.

2.1 Type and plants distribution

In the end of 2011 there was an available heat capacity for district heating of 7.000 MWt divided in 16% of cogeneration dedicated plants, 15 % of thermoelectric power that yield part of the heat for district heating, 9 % includes biomass and municipal waste system and 1% geothermal plants. One thing to note is the presence of integrator boiler that represent the major part of the installed power with a value closer to 59% of the overall power.

Table 6: Power of the plant at the end of 2011

	Electric power [MW]	Heat power [MW]	Number of plants
Steam turbine (fossil fuels)	157,7	347,4	4
Reciprocating engine feed by gas	273,1	274,6	136
Combined cycle	258,4	267,3	8
Gas turbine	82,3	141,2	9
Gas micro turbine	0,655	0,906	4
Thermoelectric power	0	1065	3
Incinerator	0	392	/
Biomass boiler	0	197	/
Biomass cogeneration	33,3	67	6
Geothermal	0	41	/
Heat pump	0	20,3	/
Integration boiler	0	4115	/

In 2011 was produced 8645 GWh of thermal energy and only 95,4 GWh of cooling energy, as evidence that the sector of district heating cooling in Italy is very limited also due to the not need to have cooling system in the mountain area. A few number of plants present cooling system and usually the cool is produced in absorption system based near the major users using the hot water carry in the pipeline.

In the last years fossil fuels represent the principal energies utilizes in the cogeneration system and provide over the 50% of the entire energy. Another 30% of fossil fuels is used in the integrator boilers. Only 20% of the heat is product by renewable energy and includes: biomass, geothermal, municipal waste and industrial process. The rule of heat pump is very limited.

Integrator boilers represent a huge value of installed power but in relation to this, they produce a small part of heat. This is naturally thinking at the rule that they cover. These systems have to supplier heat when the load is too higher for the other systems. To Install boilers is cheaper than oversize other system and permit to work with a higher efficiently in normally condition. In other case these boilers can be activate when the main system have a problem or need maintenance.

Natural gas covers the main part between fossil fuels with more than 75% growing in the last 15 years. Excluding reserve boiler, the main system are normally cogeneration or biomass boiler. Cogeneration is realised with different solution and in Italy, there is a wide variety of system. The most important like production of heat are:

- Steam turbine
- Gas reciprocating engine
- Combined cycle
- Gas turbine
- Diesel reciprocating engine

The number of biomass system is very high but the total production of heat show that their average dimension is small (only 6,3% of the entire heat provide with district heating). The bigger stations in Italy usually exploit the cogeneration with gas or with the combustion of municipal waste.

2.1.1 Steam turbine

Steam turbine represent the first cogeneration system for the production of heat for DH. The number of these systems is limited in four plants but their dimensions are very important and are usually able to produce more than 30.000 KWh. The largest plant in Italy is in Mantova. It have a heat power of 300MWt and 139KWe of electricity. The work efficient is 0,857 but the major part is due to the heat production that reach a value of 0,633. Another import plants is based in Reggio Emilia with a power of 18,5 MWe and 46,5 MWt. The work efficent is 0,76 and also in this case the heat production represent the main part of the energy that is generate.

Table 7: Data of some steam turbine

City	Electrical power [KW]	Heat power [KW]	Global efficient	Electrical efficient	Year of built
Mantova	139.000	300.900	0,867	0,234	1978/93
Reggio Emilia	185000	46500	0,760	0,193	/
Torino	31.640	45.300	0,799	0,277	1992

Technology

One of the more important advantages of these systems is the possibility to use a huge variety of fuels: gasses, liquid or solid. In addition, the quality of these fuels can be low as oil, coal, or municipal waste. The reason is find in the combustion, which is made in a boiler that produce steam to feed the turbine and the fuels is not used directly in the machines. The basic scheme of this plant is easy and it includes a pump that increase the water pressure at the level needs in the cycle. The boiler in which water forms steam and after it is superheated. The vapour enters in a turbine where expands, decrease its pressure and temperature. Turbine converts the energy of steam in mechanical energy. After that, the vapour usually have a pressure about 0,05 Bar and 35°C, but this depend to the plant dimensions and to the temperature of cold sink. The cold sink is necessary to close the cycle and with a heat exchange the steam condenses and heat is rejected in the environment. Temperature of 35°C is much low to produce heat for district heating and it is necessary to stop the steam expansion a higher pressure, for example, 3-5 Bar and the condensing temperature is more than 150°C. The mechanical energy obtained is reduced, but now, is possible to exploit the condensing heat of steam. There are many configurations of steam turbines with different complexity and capacity to separate the heat and electricity production but in all case the electricity production decreases and the recovered heat is not obtained only with rejected energy. These plant represent the solution for larger plants and the average power is usually included between 0,5-100 MW. The electrical efficiently is 20-35% and cogeneration rate is 0-1,5.

Benefits:

- Possibility to use many types of fuels.
- The heat is in form of steam and it is provided at the temperature that you want.
- Long life cycle of system (25- 35 years).

Disadvantages

- The electrical efficiently is reduced.
- Important plant dimensions.
- Slow reposing to load change.

2.1.2 Gas Turbine

Gas turbine cover a very large range of dimension. There are some micro-turbine that produce only few hundred of KWt and plant with power more than 50.000 KWt. The installed turbines seems to be old and never one has been installed in the last years. In 2011 has been dismissed 3 turbines with entire power of 37,7 MWt.

Table 8: Data of some gas turbines

City	Electrical power [KW]	Heat power [KW]	Global efficient	Electrical efficient	Year of built
Osimo	3.500	7.200	0,503	0,322	1990
Roma	19.033	44.400	0,626	0,262	1983
Rovereto	14.881	18.573	0,69	0,5	1999
Varese	5000	110000	0,765	0,22	1992

Technology

These systems work in according to the Briton-Joule cycle. The cycle is composed by four polytrophic transformations. The air is aspire to the environment and compress. After that, in the chamber of combustion, the fuel is injected and the combustion starts. Gas increase its temperature and energy. Finally, the gas expanded in the turbine and convert its energy in mechanical. Part of mechanical energy is used to compress the inspire hair and the remaining to produce electricity. The hot gas release in the environment have a high temperature usually around 500°C and a pressure a bit superior to the external ambient. The easy method to use this heat is to pone a recovery boiler at the end of the turbine. The size range is large, with small system of 0.2 MW until 100MW. Electric efficiently is included between 22-37% and the cogeneration rate 0,5-1,1.

Vantages:

- Reduction dimension and initial cost
- Heat source at high temperature
- Quickly response to load variation

Disadvantage:

- Necessity of fine fuels
- Necessity of periodic check for maintenance
- Not adapted to frequently switch on-off

2.1.3 Reciprocating engine

Reciprocating engines are the more diffuse in the sector of Italian cogeneration and are feeded by natural gas and in rare cases with gas oil. A great number of DH system have almost one of these machines. The principal vantage of reciprocating engine is the small power and the possibility to decrease very quickly their power. Always they are use in parallel with the possibly to modulate better the power when the heat computation is low. The maximum dimension usually does not exceed the 5-10 MWt. In 2011 were active 136 reciprocating engine. A particular situation is visible in the station of Coredo (TN), where the major part of the installed power is due to a Biomass boiler 2,4 MW , a reserve gas boiler 1,4 MW and finally a reciprocating gas engine with 0,52 KWt. In 2011, the cogeneration system produced the 65% of the entire request of heat and it worked for 7162 h/year with an average power of 91,1% respect the nominal value. This evidence that the gas engine is used in the summertime to produce hot water.

Table 9: Data of some reciprocating engine

City	Electrical power [KW]	Heat power [KW]	Global efficient
Acqui Terme	1.942	1.926	0,767
Bologna	2.134	2.770	0,775
Bologna	801	968	0,753
Bologna	4.040	5.000	0,68
Mantova	3.300	3.100	0,759

Technology

Reciprocating engine have a large range of power but the power is usually limited. These systems work in according to the Diesel or Otto cycle. In engine with Otto cycle, the air is aspire in the cylinder as a mixture with fuels and after is compressed. The combustion begin when the spark plug starts it. These engines are usually feed with natural gas and their use is common in the new cogeneration system. In Diesel cycle, the pure air is compressed and after that, the fuel is injected in the cylinder and the combustion starts due to the high level of pressure and temperature. Diesel engine function whit diesel fuel or natural oil.

There are many heat source in a reciprocating engine and the heat is provided in two different level of temperature

- Hot gas release: this represent the source at higher temperature. The gas has a temperature included between 400-500°. The way to use this heat is to pone a recovery boiler on the exhaust hot gas and exchange heat with the flow of water. This source can produce also steam a medium pressure for example to use in some industrial process. The hot gas have a energy equal 30-35% of the entire energy burn in the engine
- Cooling water: this is the water uses to cooling the engine, temperature of this source usually don't exceed the 90°C and it can use only for the hot water production at low temperature. This source has an energy of 15-20% of the combustion energy.
- Lubrication Oil: the temperature is like to cooling water but the available heat is only 5-7% of the energy realised in the combustion
- Supercharged air: is present only in the supercharged engine, the temperature is similar to the water temperature of cooling and the recoverable heat power is similar to the oil.

The total heat that is possible to recover is the 50-60% of the burned energy. About half of this power is available to high temperature. The electrical efficient is about 30-45% and the cogeneration rate 0,5-2.

Vantages:

- Possibility to use gasses and liquid fuels included the renewable fuels like natural oil or gas
- High electric efficiently until 50% of the nominal power.
- Large field of power in the small range.
- Possibility to have a lot of switch on and off

Disadvantage:

- High NOx emission
- Higher cost of maintenance and life cycle of 10-15.000 hours for the small system and 15-20 years for the other

2.1.4 Combined Cycle

The overall production of combined cycle is closed to the reciprocating production but the average dimension is considerably higher. There are in fact only 8 plants of this type in Italy. The average dimension of these plants varies considerably and range is from 9 MWt to 82 MWt. The relation between electricity and heat nominal power change from case to case. In some case, the production of heat is greater than electricity and in other case is the opposite. The real efficiently of this system is not so high and it is included between 60-75%. These values are very low in relation to the maximum possible. This is due to the economically convenience to use this system principally to produce electricity. System with 50-100 MW of average dimension could have electricity efficient between 45-49% and the only power production is able to cover the cost of production although the heat is rejected in the environment.

Table 10: data of some combined cycle

City	Electrical power [KW]	Heat power [KW]	Global efficient	Electrical efficient	Year of built
Alba	20.000	30.000	0,715	0,420	2007
Bologna	6.300	9.300	0,645	0,288	1994
Cremona	13.000	14.000	0,70	0,369	1992
Genova	31.000	33.000	0,62	0,385	1994
Reggio Emilia	56.000	52.0000	0,62	0,409	/

Technology

Combined cycles are composed by a gas and steam turbine. The steam turbine is feeded by the hot gas release from the gas turbine. With the rejected heat is infect possible to produce steam with sufficient high pressure to move the turbine. The elements are the same that in the two separate plants. For heat production for district heating is possible to utilized the condensing heat of steam. This plants are characterized by high electric efficiency usually like 45-55% and their use is convenient also reject in the environment an important part of the condensation heat.

Vantage:

- High efficiently

Disadvantage:

- High plants cost
- Use only a fine fuels like natural gas

2.1.6 Thermoelectric power

Thermoelectric powers include all plants that produce heat for district heating but they wasn't designed for this purpose. They are connected with the grid only because located near the pipeline of district heating.

Usually this plant are represented by steam turbine. The low-pressure turbine taps the steam. The losses of pressure is very limited and includes in 2-5 bar and depends to the thermal temperature of the heat that you want produce. The drop of electricity production is about 0,15-0,20 KWhe for every KWht.

This group considers some private cogeneration system that produce electricity and heat for internal used and sometimes a part of heat is sell to the district heating system. This solution is more common in North-Europe where the big plants are feed from many different companies.

Table 11: Data of some thermoelectric plant

CITY	**Heat power [KW]**	**Global efficient**	**Heat efficient**
Settimo Torinese	120.000	0,510	0,007
Cassano D'Adda	30.0000	0, 511	0,004

2.1.7 Energy from waste

The energy from municipal waste represent the second import fuel after natural gas and cover the 12,6% of the entire energy deliver from district heating. This value is almost two times high then biomass. The waste are not selected and they included recyclable and non-recyclable part and result unavoidable to use a small part of fossil fuels for the pilot flame. For example in Ferrara, the plant burn waste and the pilot flame function with natural gas with a consumption of 30 GWh/years against the compunction of waste is 260 GWh of renewable waste and 86 GWh of non-renewable. The bigger plant in Italy is located in Brescia and it have a power of 300.000 MWht and present a very high efficiently.

Table 12: Data of some energy from waste plant

City	Electrical power [KW]	Heat power [KW]	Global efficient	Electrical efficient	Year of built
Bologna	22000	27500	0,36	0,256	2004
Como	5500	5800	036	/	/
Ferrara	16000	29000	0,429	0,194	1999
Brescia	139.000	300.000	0,867	0,234	1998
Cremona	6000	12.000	0,424	0,1	/
Desio	5.400	15.000	0,259	0,08	/

2.1.8 Biomass boilers

Biomass boilers have a good diffusion in the village in the Alps and plant feded by them are characterize for a limited dimension of the grid and number of users. In 2011 they produced 7,2 % of the entire heat provide from district heating. Normally these systems are installed in mountain village in the north Italy where the weather condition are more strict and sometimes the village aren't connect with natural gas grid and the only other alternative is represented from gas oil boilers. In the Alps, there are a great presence of wood that make easy and cheaper to utilise these boilers. The average power is less than 3 MWt and the biggest plant arrives to 25 MWt in Cavalese and S. Martino Di Castrozza but only 8 MW are covered by biomass boiler and the remaining power is covered by integrator boiler respectively function with natural gas and diesel.

Technology

The more common biomass boiler are usually feed by wood, chips or pellet. Chips and pellet boilers usually have an automatic charger system. Pellet presents a low water content and the combustion don't present particular problem. In the chips plants the matter can have a water content about 50% and this needs some particular devices to permit the combustion. This boiler have a particular moving grate that facilitate the combustion. Feeding system needs a particular structure and a great dimension storage because the density of this matter is usually low. In the new system the emission are kept down using a particular electronic system that control the combustion and adjust the correct quantity of air and fuel. These new system have less problem to partialize the load having an efficiently combustion. The instant efficiently can exceed the 90% like the normal gas or diesel boiler.

2.1.9 Integrators boilers

Integrator boilers produce heat with the direct combustion of fossil fuels. Usually these boilers have the purpose to cover the peak of demand. The installed power is very high and represent almost the 50% of the overall power and sometimes can reach value more than 70%. They have to handle probably damage to the main system, the naturally and frequently stop for maintenance.

Gas or gas oil boiler usually are not use alone in DH system because they don't guarantee saving of primary energy because normally the losses in the district heating pipeline cancel the vantages to produce heat in larger and centralised boiler considering the seasonal efficiently of production. An example of this is the district heating plant in Castelmaggire (BO) built in year 2009 that presents only two-gas boilers whose consumption of primary energy is major that in the replace systems, considering a seasonal efficiently of 90%. Using only gas boiler could bring some economic vantages due to the less cost of gas for district heating that benefit of discount tax and trading price.

2.2 Regulations that advantage DH in Italy

National regulation about energy efficiency have an important rule and can discriminate in favor of one or other heating system. These rules have an important impact to DH and tends to favorite its use, for example saving the switch cost and creating the condition to reduce them for DH use and disadvantaging other systems.

2.2.1 Preparation for the connection

National regulations required that all new buildings located less than one kilometer from DH pipes must be prepared for the connection with DH favoring a future connection. The connection is not necessary but result immediately convenient if the installation of other system comport other extra cost not present with DH connection. Other regional regulation push in the same direction with the obligation for buildings with more than four flat to have a centralize system of heating making easier a future connection with DH. The real duty, to connect with DH is present only for social housing in which habitants are obligate to use this technology.

2.2.2 DH to satisfy environmental duty

"*Articolo 11 of D.Lgs 28/2011*" obligate to integrate renewable source in the production of heat and cold in new building or subject to important refurbish make after 1/6/2012. The non-observance of law expect the possibility to obtain the habitability of the house and expect to cover at least 50% of the energy for DHW with renewable. This duty is not applicable if the house is connect with DH that cover the entire energetic consumption considering it a renewable source.

2.2.3 User incentives

National regulation expected some incentives for the user of DH. These incentives are present only for biomass and geothermal system and are present as tax rebate for the company that provide the service. Two are the incentives present. The first has been introduced with "*L. 23/12/2000 n. 388, art. 29*" and give a contribute of 20,658 €/KW for the installation of heat exchanger. The second is a reduction of taxation that was present on fossil fuel and has been applicate as tax rebate for the DH manager but the benefit is only for the final customer while the company represent only an intermediary between this last and the government. The amount of this incentive was 25,82 €/MWh and was introduced for the first time with "*Legge 23 dicembre 1998, n. 448*". This amount was reduced of 15% in the *"Legge 147/2013",* financial low of 2014.

The tax rate of IVA apply to the sale of heat have a reduced rate and it is equal to 10%

2.2.4 Green certificates

Cogeneration system offers a real opportunity to decrease the CO2 production increasing the efficient in the use of primary energy. European country want to increase the utilisation of these systems as indicated in the Directive 2004/08/CE that promoted the cogeneration. In this paper are indicated the requirements to have a high efficiently cogeneration system and this depend to the size of the plants.

- In micro and small plant (less power 1MWe) is sufficient that the system save energy in relation to the separate system
- In the other system the energy save have to be at least 10% respect the separate production

The saving of energy is calculated in according to a formula propose in this paper in which is necessary to insert the cogeneration and separate production efficiently. The result index is call PES (Primary Energy Saving) is:

$$PES = 1 - \frac{1}{\frac{\eta_{t,CHP}}{\eta_{t,REF}} - \frac{\eta_{el,CHP}}{\eta_{el,REF}}}$$

PES = primary energy saving

$\eta_{t,CHP}$ = thermal efficiently in cogeneration

$\eta_{t,REF}$ = thermal efficiently as reference in the country for separate production

$\eta_{el,CHP}$ =electric efficiently in cogeneration

$\eta_{el,REF}$ = electric efficiently as reference in the country for separate production

The value for the separate production change for every country and depends to the average situation relatively to the internal production.
Law n°239 of 24 august 2004 introduce the possibility to emit green certificate for the energy produced in cogeneration system combined to district heating in relation to the part of heat provide in the plant grid. Green certificates are share emit to GSE that guarantee the production with renewable energy (or other system). These shares are buy to the company that produce electricity but are not able to produce the 10% of energy with renewable method. In this way, they pay to have these shares and the plant owner get economic advantages. The rules to obtain green certificates are printed in the DM of 24 October 2014 that explain how calculate the electrical energy and the modality to obtain the certificates. For every part that composes the cogeneration system laced to district heating the quantity of energy that can request green certificates is

$$E_{CV} = H * C$$

E_{CV} = amount of electrical energy that can request the green certificates

H = part of thermal energy real uses in district heating

C = value that depend to the type of system

2.2.5 White certificates

In according with EEN 9/11 district heating plant feed by biomass is a system that contributes to reduce the CO2 emission. For this reason DH plant can received financing with the system of white certificate. Allegato A to ENN 9/11 includes this type of plant in kind of efficient II, because comport a reduction of natural gas consumption. Every TOE of energy saved is related with the emission of 1 TEE a title that certificate the saving. These titles are sold in a telematics market and are bought from the company that have to guarantee a fixed CO2 saving but can't respect this limits themselves.

The quantity of TEE, for DH, are released when a new plant is realise and the saving of CO2 must be certificate with an analytical method that considers the real energy produced with biomass boilers. For type II of TEE the minimum amount possible to obtain new title is a saving of 40 TEP. Moreover for the construction of new plant, white certificate can be released also when new user are connected with DH and the provide energy from the station increase.

2.2.6 Tax advantages

The consumption of natural gas in district heating have also tax advantages that comport a sensible reduction of the price. The real vantage to use natural gas in cogeneration is the possibility to consider the consumption as industrial which present a lower taxation thought the entire amount of heat or electricity is used for civil purpose. In particular, the advantages on the natural gas consumption are:

- Reduction of consumption tax
- Reduction of regional tax
- Reduction of IVA

Table 13: Advantages tax for natural gas for DH

	Civil	Industry/DH
Consumption tax	0,1733 €/NmC	0,01249 €/NmC
Regional tax	0,0155 €/NmC	0,01249 €/NmC
IVA	20%	10%

3. Foundations for a new project

The plant that you want to design regard only a small part in the city of Verona and the dimension is limited to 42 building with an actual population of 1200 people. After an investigation in the Italian situation of district heating, in particular focus on the small plant, is possible to make some observation and see, as the dimension of this plant is similar to the plant present in mountain and feed with biomass. The variety and the presence of many type of biomass mater bring to study and research the possibility to use different kind of biomass present in the territory. Normally district heating system feed by wood or chips are present only in mountain for the huge presence of wood. Result really interesting and innovative to study the behaviour of a system feed by straw as present in other European country like Denmark.

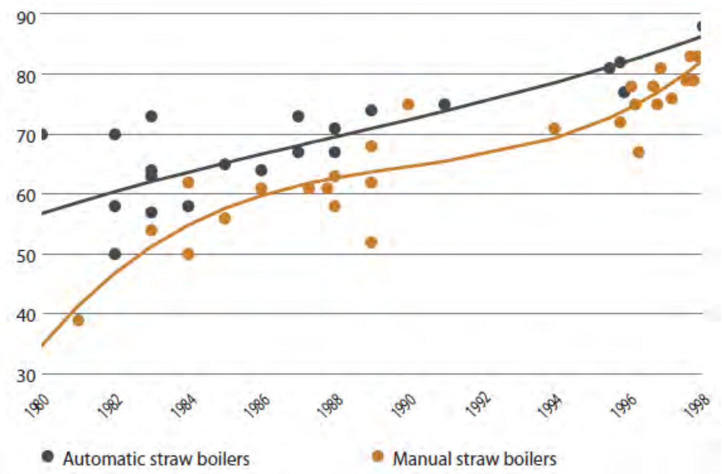
Other solution like gas boilers has not considered because they are not suitable for the Italian situation. However, these boilers are used as reserve boiler and their presence is usually indispensable in every district heating system to guarantee reliability. The choice to use straw system is validate to the high quantity of this matter nearby the place and to the good price in relation to the chips

3.1 Straw boilers in Europe

Denmark is the only European country that is completely energetically independent and district heating cover 62% of the population . A large part of the district heating plants is feed by renewable energy but in Denmark beyond the normal biomass has borne another important chain, which uses straw. Straw provided 2500 GWh of energy in 2012 and represent the 6,6% of the overall energy computation for district heating .

The first straw boilers appeared in the 1970’s and were systems utilized in farms. The first boiler functioned with small balls but their dimension increased quickly and these boilers had had a fast development. Now, is possible to recognise two types of straw boilers: manually heated plants, also known as portion plants, and automatic heated plants. In the manually plants the balls are charge manually with front loader, this configuration is very economy but need more time to charge new balls and remove the ash. Automatic heating plants consist in a straw boiler and a supply system, which consist in a conveyor and a mill that breaks the straw in small pieces before enters in the combustion chamber. The efficiently of the first system was about 30-40% and when this boiler worked it was dangerous for the neighbour. However, in 1976, the Danish Agricultural Research Institute, began testing straw boilers and helping the manufacturers with product development. Now the system could be an efficiently of 80% and more.

Graphic 2: Efficient of straw boiler during the time



Meanwhile, boilers became more efficient, the emission of carbon monoxide dropped significantly. Carbon monoxide per se is not harmful for the surroundings in small doses, but can be used to know the quantity of the other substance. If there is a lot of carbon monoxide in the smoke, there will also be a number of other harmful substances emitted. This includes for example soot and tar that could be carcinogenic. The presence of these substances evidence an incomplete combustion, and the most sensible way to remove these, is to improve the combustion temperature so the substances are burned off, while at the same time the straw is better utilised.. Straw and other types of biomass create gasses, which do not ignite until the temperature has reached around 800-900 degrees. If the temperature falls too low, the gasses will not burn before and they will emit through the smokestack, which leads to low efficiency and environment damage.

An important successful in the field of straw boilers was the introduction of straw boiler that produces steam for a turbine and for district heating. The Funen power plant has been working from over 50 year but only from 2009 has been activated a new line that burned straw. This plant deliver heat to the near city of Odense, the third city in Denmark and its dimensions are very considerable. This new line works separately to the other system and it burns 170.000 tonnes of straw annually corresponding to 28 tonnes per hours. Close to the plant, a straw storing facility has been established with a capacity of 2,300 straw bales weighing 580 kg each one. The straw arrives on trucks from farmers located in ala the island of Funen. The new straw unit will replace approx. 100,000 tonnes of coal and consequently reduction of CO2 emission of about 245,000 tonnes every year. The electrical capacity at normal load is 35 MW equal to 20 % of the consumption in the nearby city of Odense. The heat capacity of the unit is 84 MW equal to 25 % of the consumption in Odense. The steam reach a temperature of 540°C and a pressure of 110 bar.

3.2 Italian possibility for straw boilers

The possibility to realise in Italy systems that function with straw depends directly to the agricultural sector. That needs to analyse the Italian situation and understand if there are some possibilities to utilise a system like in Denmark. The plant that we want to study will be place in the countryside and the straw reserve are sure nearest then the wood. The handling of straw could be easier and cheaper than the wood because in the countryside is possible to use machinery of great size to pick up this resource without the directly use of handwork. Before starting this analysis is better to explain, what is straw and which are its proprieties.

3.2.1 Straw propriety

Straw is an agricultural by-product derives from the dry stalks of cereal plant after that the grain has been removed. Straw makes up about half of the yield of cereal crops such as barley, oats, rice, rye and wheat. Actually, the main use, in Italy is the bedding for cattle. It is usually gathered and stored in a straw bale, which is a bundle of straw tightly bound with twine or wire. Bales may be square, rectangular, or round, depending on the type of baler used. The content of water is usually 10-20% and specific heat for dry matter is slightly higher than the wood. The quantity of ash produced with the combustion is higher than the wood but this substance can be readmitted in the environment.

Table 14: Straw proprieties in relation to other fuels

	Yellow straw	Wood chips	Natural gas
Water content [%]	10-20	40	0
Volatile components [%]	>70	>70	100
Ash [%]	4	0,6-1,5	0
Carbon [%]	42	50	75
Hydrogen [%]	5	6	24
Oxygen [%]	37	43	0,9
Chloride [%]	0,75	0,02	-
Nitrogen [%]	0,35	0,3	0,09
Sulphur [%]	0,16	0,05	0
Caloric value (water/ash free) [MJ/Kg]	18,2	19,4	48
Caloric value, actual [MJ/Kg]	14,4	10,4	48

3.2.2 Straw availability

The availability of straw depends firstly to the cultivation of cereal that is shown in the table. Date are referee respectively to Italy, the region of Veneto and the province of Verona. The most important values is relatively to the city of Verona because is the city in which the plant will be designed. Having an availability of straw near the plant is infect a good start to keep low the carry cost and the consumption of fossil fuels for these actives. In the value, show in the table 15 is not present corns that in Italy and principally in Veneto represents the main cultivation. This decision is made consider that the yearly harvesting of corn is performed in autumn and the straw have usually a high quantity of water, about 35-45%, and the weather condition in this period of the year do not permit any possibility to dry this matter naturally. For the utilisation of these resource are need some treatments like the palletisation that need particularly machines and process with other extra cost, over the price of the matter, compatibles in 50-80 €/ton.

Table 15: Straw availability

Cereal	Italy(2011) [Kton]	Veneto (2009) [Kton]	Verona (2009) [Kton]
Common wheat	531,1	100,1	16,8
Hard wheat	1194,9	6,3	0,5
Rise	242,5	3,2	1,8
Oats	126,9	/	/
Barley	268,7	10,2	3,18
TOT	2364,1	119,8	22,28

The combustion of other cereals straw is made directly without any dry process because the water content is about 10-20%. With the values of cultivate area is estimate the yearly production of straw: primary in Verona, Veneto and in Italy. The total area with cereal, without corn, in Verona is 22 thousands of hectares and the average production for hectares is about 3-5 ton/year. Considering 4 ton/year the overall production of straw in Verona is about 90 thousand of ton.

Table 16: Straw potential

	Italy	Veneto	Verona
Area (thousands of hectares)	2364,1	119,8	22,28
Quantity (thousands of ton)	94000	480	90
Energy (GWh)	376000	1920	360

Another aspect to consider is the real availability of this resource because part of this has already used for other purpose. Actually, the main use is for cattle bedding, food of animals or industry but these in according with Itabia cover only the 50% of the entire production .

An excessive utilise of straw could increase the price and move some user to change matter an example to use the corns stalks for the cattle bedding.

Considering a heat capacity of 14,4 MJ/Kg equal to 4 KWh and the entire availability of straw, the total energy is 360 GWh/year that correspond to 40MWh of energy for 8760 hours.

3.2.3 Straw price and convenience

The price of the straw change a little for the different kind of cereals. In Verona and in Italy the more cultivate is wheat and this is taken as reference. Price report in the table is the average registered in the last four years. In according to the commodity exchange of Mantova it was about 47,5 €/ton and the average of the last 4 years was 56,1 €/ton.

Table 17: Price of straw

Year	Minimum price [€/ton]	Maximum price [€]	Average price [€]	Including transport [€]
2013	52	57	47,5	72,6
2012	42	47	44,5	84,5
2011	70	80	75	120
2010	45	55	48	100.8
Average	52,5	59,8	56,1	94,5

To make more significant the price is better to calculate the price for every KWh and compare with the other fuels that could be utilise in a district heating system in Verona.

Table 18: Price for KWh of energy for some fuel

Fuels	Price	Specific heat	price [€/kWh]
Straw	56 €/ton	4 KWh/Kg	0,014
Natural gas (industry)	0,40 €/Nm^3	9,5 KWh/Nm^3	0,042
Natural gas (civil)	0,85 €/Nm^3	9,5 KWh/Nm^3	0,089
Wood (chips) (M 45%)	40 €/ton	2,6 KWh/Kg	0,015

The price of biomass for KWh result low than natural gas considering the industry and the civil cost. The price of wood and straw is not simple to define because is bound to the regional resource and the transport cost represent an import part of the final cost but the price for WKh is about the same. To determinate the KWh cost important is the water content that for the straw is very low at the harvesting while the chip present an higher humidity (also 55%) decreasing the net calorific value.

3.3 Location for the new plant

District heating plant that you want to design will be placed in Verona, a city with 266.000 people located in north-east of Italy. In this city is already present a district heating system but it covers only a part of the city. The present plant is managed by AGSM and the heat generation is made with nine reciprocating gas engine, one combined cycle and some integrator boilers. The system has an installed power of 57 MWhe and 181 MWht.

The chosen area is called Palazzina and it includes building in Via Palazzina, Via Ravenna, Via Cervia, Via Rimini, Via Riccione, Via Romagna and Via Cesena. This part of the city has been chosen because it is distant to the other pipeline of district heating present in Verona and for the convenient configuration of buildings. The major part of the buildings in this district are multifamily houses, structure with almost three floors that comport a good value energy demand for meter of pipeline. The chosen buildings are regrouped in a small area and the length of the tube will not have long distance without users.

Figure 1: Map of the district with indicates the area for the boiler house

The area is approximately a rectangle with dimension of 616 in the great side and respectively, 148 and 271 for the smaller side that have different measure. The zone have an area of 110.000 m^2 and includes 42 buildings. The overall net area of the buildings is 39.000 m^2 with a residential population of 1245 people and 534 flats. The space to build the boiler house is present in the field around the district. The area is kept distant from the other buildings to avoid the presence of noise and other problem that biomass boiler could create. Detail of each Building is report in the follow table.

Table 19: Details for the buildings present in the area

Building number	Number of Residents	Number of flats	Number of Floors	Plant area [m]	Total area [m^2]
1	152	55	3	2510	5271
2	15	8	3	218	459
3	10	4	3	185	388
4	27	13	3	430	903
5	3	1	1	137	96
6	3	2	2	110	153
7	22	10	3	341	716
8	41	17	3	532	1117
9	1	1	2	119	166
10	3	2	2	111	156
11	24	9	3	239	502
12	20	9	3	242	509
13	5	2	1	127	89
14	14	7	3	250	525
15	17	8	3	238	499
16	4	1	2	124	173
17	18	7	3	195	409
18	17	6	3	223	469
19	16	6	3	211	443
20	18	9	3	129	271
21	12	8	3	255	535
22	12	5	3	261	547
23	2	1	2	76	106
24	6	2	2	229	321
25	16	9	3	254	532
26	52	24	3	704	1479
27	40	19	3	704	1479
28	33	22	5	304	1064
29	35	22	5	300	1049
30	34	13	4	278	779

31	73	35	5	517	1808
32	20	13	4	209	585
33	33	17	4	279	780
34	53	27	8	535	2996
35	18	16	4	209	585
36	33	17	5	320	1119
37	38	17	5	314	1099
38	62	31	7	362	1772
39	58	31	7	362	1772
40	78	31	7	362	1772
41	54	31	7	362	1772
42	53	31	7	362	1772
TOT	1245	599	/	14224	39039

3.4 Thermal load

The calculation of the energy consumption for the selected buildings presents some problem, first the possibility to realise accurate energy analysis. One of the most accurate method could be to know the consumption of natural gas for every flat or building in case is present a centralise system. The chosen way is different and represents only an estimate based on the possible energy consumption for each building. For this purpose has been used some typical dates for every typology of building in relation to them year of construction.

The buildings are divided in 4 categories: single-family house, terraced house, multifamily home and condominium.

- Single-family house: characterized by a unique property with one or two floors, isolated or adjacent to another building
- Terraced house: consists of a single housing unit, with one or two floors, adjacent to other units
- Multifamily home: building of small size characterized by a limited number of flats (2-5 floors, maximum 15-20 units), usually the flats present at least two wall directly outside.
- Condominium: large building characterized by a higher number of units.

These typologies of building are divided in other four categories that represent the year of construction. The district chosen is a residential with relatively new buildings.

For these reasons, the oldest band includes building no older then 60s years. Every band represents a particular period with a different system of construction and material used.

There are a lot of building typologies that are used in Italy but usually, they are massive structure and their components are usually bricks and concrete. The year of construction is important to estimate the grade of isolation because the techniques of construction has been changed a lot in the last half century. A simple considerations, take a reference in this study, are reported here:

- Before 1976 there were no thermal insulation and the thermal resistance was due only to the thickens of the wall.
- 1976-1991: it is considered a very low insulation with Uwall = 0,8 W/m^2*k
- 1991-2005: it is considered a medium insulation Uwall = 0,6 W/m^2*k
- After 2005 thermal insulation is regulated by D. Lgs 192/2005 that establishes the minimum values of insulation.

The windowed areas present also different type of solution and it depends to the glass, (single, double and its thickens) the material and shape of the frame. Before 1975 the U value was usually included between 4,9-5,7 and after 1976 is possible to find higher performance values like 2,8. After 2005 has been introduced solution really more performance.

Another factor to consider in the energy consumption is the efficienct concerns to distribution, regulation and emission. The production efficiently is useless because the scope is to calculate the gross heat that every building need and not to calculate the primary energy consumption. The heat demand represents how much the building consumes and it is independent to the production efficiently. The values are obtained from UNI ISO 11300 I and they are calculated for every band of building not considering the different type of plant present inside. The choose value are reported in the table.

Table 20: Efficiency of heating system

Year	Distribution	Regulation	Emission	Overall
1960-1975	0,89	0,91	0,94	0,75
1976-1990	0,89	0,91	0,94	0,75
1991-2005	0,89	0,97	0,94	0,81
2005-	0,97	0,97	0,99	0,93

For every type and period of construction there are given values of yearly energy consumption for square meter. The adopted values are provided by building Typology brochure- Italy in according to the previous consideration and build solutions. The values are showed in the table and they are referred to the Climatic zone "E" in the range of 2100-3000 degree day. This assumption is correct for the city of Verona that presents 2468-degree day and it is sited in the middle of this range.

Table 21: Energy consumption for meter square.

Year	Class	Single-family house [KWh/m^2year]	Terraced house [KWh/m^2year]	Multifamily house [KWh/m^2year]	Condominium [KWh/m^2year]
Class	/	A	B	C	D
1960-1975	1	280	241	153	134
1976-1990	2	136	113	105	67,6
1991-2005	3	82,3	85,1	70,3	62,5
2005-	4	67	65,8	40,5	36

The subdivision of buildings in class is made only with comparison the external view with some picture present in the brochure and looking some detail as the type of window present in the building that can give some information about the year of construction.

The areas of the buildings are obtained from the website of municipality of Verona. In this web site is possible to calculate the overall gross volume of the select buildings, the high and the plant area. In other section is indicate the number of flats and the number of residential people for every structure. The value of area provided by website is purified by a frame that represents the projection of the roof. The number of floors is counted directly watching the building conformation. To consider

only the net area, the area of each floor is multiplied for a factor 0,7 which consider the relation between gross and net area occupied by walls and stairwells. The overall area of each building is multiplied by the yearly consumption established for every structure and considering the efficiently of distribution, emission and regulation.
To estimate the energy consumption for domestic hot water (DHW) is used the UNI ISO 11300 II. The overall surface of every building is divided for the number of present flat and after is calculated the average water computation for every flat. The regulation for residential buildings offers to calculate a parameter called “a” only function of the single flat area. This value is calculated as:

$$a = 4{,}515 * S\hat{} - 0{,}2356$$

The water consumption is obtained multiplying this value for the area of each flat.

$$V_{day} = a * S \quad [l/day]$$

The energy consumption is calculated considering a difference of temperature of 25°C and an efficiently distribution of 95%. Hot water consumption is considered constant during the year.
This value represents only a small part of the overall energy demand but it presents some important aspect to consider. It is the only presents in the summer time and it will need a particular design and management. Hot water required is also concentrated during a short period, during the day, and it can create high picks of demand visible especially in summer time.
The class in which every building has been inserted is report in the table number 22 with the value of energy for heating and DHW. For the entire area the yearly energy consumption for heating is 4396 MWh while for DHW is 679 MWh.

Table 22: Energy consumption for the buildings

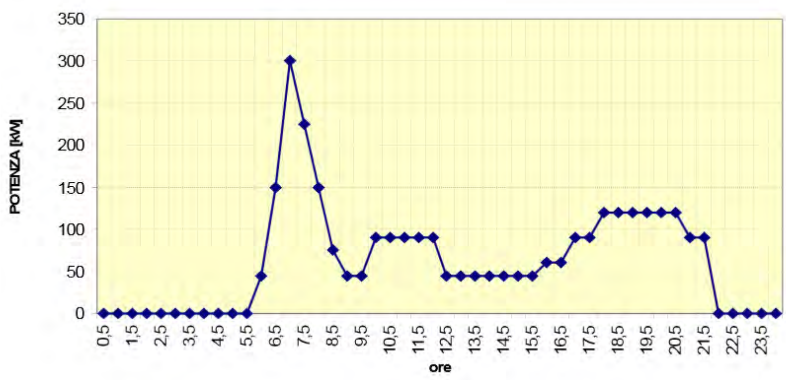
Building number	**Classification**	**Heat energy [MWh/year]**	**DHW Energy [MWh/year]**	**Peak of power [KW]**
1	B3	553	86,1	439
2	C2	64	8,4	51
3	C2	54	6,3	43
4	C1	184	15,9	143
5	A1	35	1,5	27
6	A1	57	2,6	44
7	C3	62	12,5	50

8	C3	96	19,9	78
9	A1	61	2,3	48
10	A1	58	2,6	45
11	C1	102	9,3	80
12	C1	103	9,4	81
13	A1	33	1,7	26
14	C1	107	9,1	83
15	C1	101	9,0	80
16	A1	64	2,4	50
17	C1	83	7,5	65
18	C2	65	8,0	52
19	C2	62	7,7	49
20	C3	23	5,8	19
21	C2	74	9,5	59
22	C2	76	8,6	60
23	A1	39	1,6	30
24	C2	45	4,6	35
25	C2	75	9,7	59
26	C2	207	26,8	163
27	C2	207	25,4	163
28	C3	92	20,4	75
29	C3	981	20,2	74
30	C3	6	14,2	54
31	D3	139	34,2	113
32	C3	51	11,4	41
33	C3	68	15,1	55
34	D3	144	33,0	117
35	C3	51	12,0	41
36	C3	97	19,9	78
37	C3	95	19,7	77
38	D2	160	32,7	128
39	D2	160	32,7	128
40	D2	160	32,7	128
41	D2	160	32,7	128
42	D2	160	32,7	128
TOT	/	4396	679,4	3653

3.4.1 Daily distribution

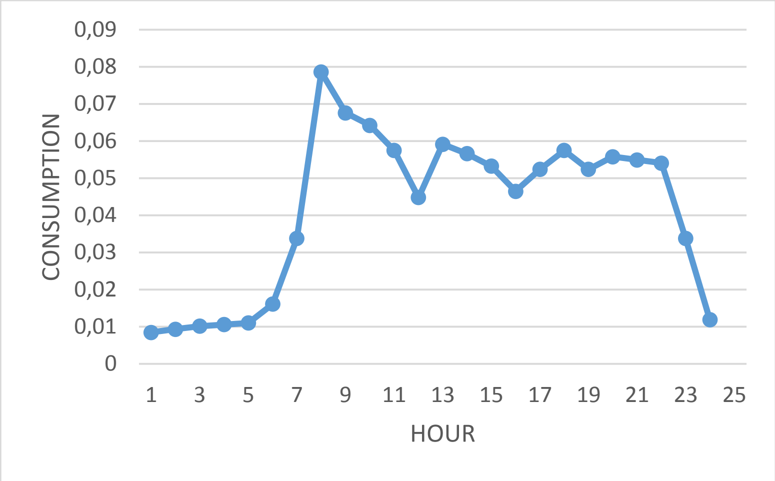
Total energy demand expressed like a daily heat demand is not very useful to design and simulate the behaviour of district heating plant. During the day, the demand of heat changes to hour in hour and in some part of the day it is low and virtually nothing. For this reason is better to estimate a daily hour distribution. This profile depends in principal way to the habits of people. For example, people switch off heat in their house during the night. This behaviour, that does not bring a very significant save of energy, mostly in well-isolated building, implies very high peaks of power that in some cases can exceed the average consumption of two times. An example of this, is showed in the figure where is present a possibly building heat demand. In the morning, there is a peak of consumption that represents the 15-20% of the entire daily energy. During the day, the consumption is low but it turns high in the evening, when people usually are at home.

Graphic 3: Heating profile for a standard medium user



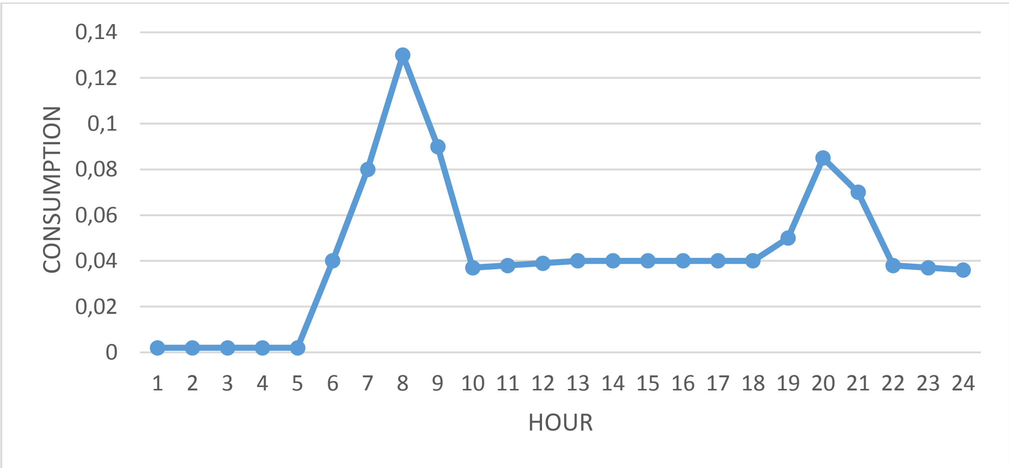
The real consumption of a group of buildings is naturally different and it is not possible that in some hours the demand is zero. There are a lot of factor that can change this distribution as contemporaneity factor and the different life style of the people. The real curve is then different and it includes many variables. For this reason, to predict the winter daily distribution has been taken historical data refers to other plant. The plant used as reference is located in Torino. This plant has a considerably higher size respect the plant that you want to design in Verona but also in this plant, the residential buildings represent the major consumption and the climatic condition are similar. The provide trend is discretized in 24 point and the value normalized. Trend is showed in the figure and it presents a peak in the morning and a value that tends to decrease significantly after evening after a little drop before midday.

Graphic 4: Daily trend of consumption in the heating period



In summer time, the trend is different because it depends only to the DHW consumption. In this period is necessary to consider a different trend. For this purpose is taken a trend suggested that presents two peaks of demand, respectively in the morning and in the evening, when usually people are at home. The consumption in the night is also improbable for evident motivations but never equal to zero.

Graphic 5: Daily trend of demand for the summer period



Accepting these trends is completely defined the daily trend for summer and winter period. If in summertime the consumption in every day is consider the same this is not true for winter where the energy for heating is directly connected with the external temperature and change every day.

3.4.2 Maximum required power

Another important value to calculate is the pick of demand present in the critical day, in which the worst predictable condition are present.

This data are obtained with a reverse calculation. The energy consumption for meter square is calculated, as said, for the climate zone "E". Energy consumption for meter square is due to the value of heat exchange for transmittance and ventilation multiplied by the number of degree-day, and after, it is corrected with the contribute of solar radiation and internal loads. Considering this last contribute constant and dividing the yearly energy consumption by degree-day and 24 hours, the result is approximately the energy demand for degree of difference between internal and external temperature.

$$\emptyset = \frac{yearly\ energy\ demand}{24 * DD} = \frac{4{,}4 * 10\hat{}6}{24 * 2468} = 74{,}22\ [KWh/°C]$$

With this value is possible to calculate the power need in relationship to the external condition in every hour of the day.

The condition, in critical winter day in Verona, usually considers the minimum external temperature of -5°C and in according to the Italian regulation the internal is 20°C. The power for only heating is then:

$$q_h = 74{,}22 * (20 - -5) = 74{,}22 * 25 = 1855{,}5KWh.$$

4. Grid design

4.1 Flow and return temperature

The flow and return temperature are connected with the production and utilization temperature. Usually for district heating plant, the solution is the coupe 120-70°C for superheated water or 90-60°C. The max possible flow temperature depend from the type of heat generator available, in our case the biomass boiler present usually a max working temperature of 90-110°C and also the straw boiler choice has this limits. Possibility is to consider a temperature lower than 90°C. That solution present the vantage to reduce the heat losses in pipeline but comport other disadvantages that seems very penalizing. Keeping a flow temperature of 80°C the heat losses (proportional to the temperature difference between the inner and outer tube) decrease only of 12,5% considering a ground temperature of 10°C. This value is further reduce considering also the return pipeline in which the temperature remain the same. Transport heat capacity of water result 33% reduced, with more pumping cost and the necessity to install tubes with largest diameter. Reducing the flow temperature comport higher initial cost for connecting station with the utilities. Other problem and more cost could be arrive from the units exchange place in every utilities that are composed principally buy a plate heat exchange design usually to work with water 90/60°C. Reducing the inlet temperature comport the necessity to increase the flow rate (if is it possible) or use a larger exchange. Both this solution comport major cost. The return temperature is also fixed and hardly can be change. Usually the connecting station produced water for heating and with this water is produced DHW in another exchange, for example in a buffer tank with steel coil. This solution with three different temperature levels need that the first fluid had high temperature to permit the production of DHW over 40-45°C without enormous exchange area. After these considerations, is decided to adopt the common temperatures 90/60° C, exploiting the wider possible difference of temperature.

4.2 Network sizing

The pipes necessary to provide hot water inside buildings are subdivide in two categories; main and secondary line. Main line are directly connected with the boiler house and they aren't directly connected with buildings. In main line are designed eight collectors that feed secondary lines. The value of power provide in every collectors is considered a fraction of the total value. This mean that in main line more is the distance from boiler house less is the design flow. Power values that are consider are due to the peak of power obtain for every building considering the daily distribution and multiplying for the factor that establish the daily trend starting to the average energy. In second line, another method is considered because the number of utilities is lower and more importance is given to contemporary factors that consider the power of the exchange units present in the flat.

For every portion of tube that connect two collector, the design load is different and calculate. To establish the dimension for every part are used engineer end economical consideration. An important aspect to analyses and considers is the water velocity that is better to keep low, to decrease:

- Hydraulic energy losses
- Usury of pipelines
- Avoided noise

Speed too low comport largest diameters with higher initial cost and more losses of heat due to the major tubes dispersing surface. Best configuration is decided for every tube section with a simple model that consider the main economical aspect like initial cost, pumping and heat losses cost for every meter of tubes. Many simplifications are made and can be resume here.

- Tubes cost is defined using the price for meter of tube in steel pre insulated with polyurethane and relatively buried cost . This price is allocated in 30 years.
- Hydraulic losses, the tube is consider smooth with a fanning friction values of 0,018 and using the Darcy- Weisbach equation.

$$\Delta P = f * \frac{\rho * v^2 * L}{2 * d}$$

Density of the fluid, ρ is 996 kg/m^3 at average temperature of 75°C. The electric price is 0,18 €/KWh and the pump efficiently 0,7. Yearly water that streams in the pipe is calculated considering the mass of water necessary to transport the overall energy with 30°C difference of temperature and hypnotizing that this flow streams in tubes always at the max rate. This aspect is not true because losses depend to the square of speed and the real behaviour is not linear. Yearly hydraulic losses are then overestimated.

- Thermal losses: are calculated with equations of heat exchange in a tube using λ < 0,03 W/m*K and a temperature difference of 65°C (between average water temperature and ground temperature). The price of heat losses is estimated in 0,09 €/KWh and is considered that they are present all the year.

$$Q = \lambda * \frac{2 * \pi * L * (T_e - T_i)}{\ln\left(\frac{R_e}{R_i}\right)} \quad [W]$$

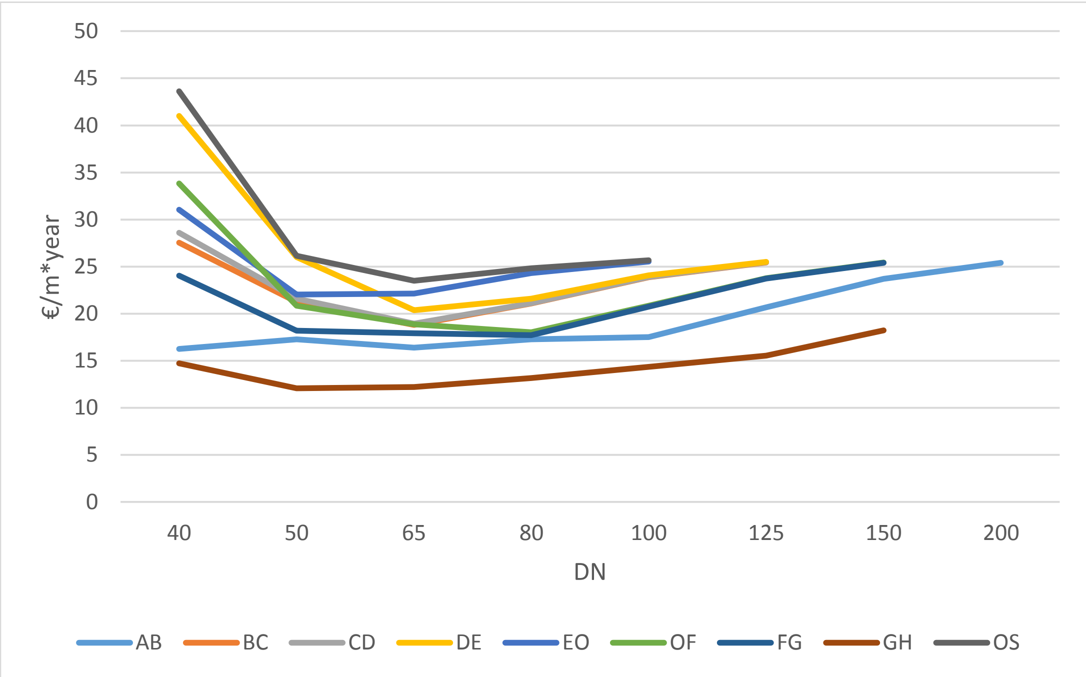
Values of peak of power is increased to consider the thermal losses present in the grid. In main line is considered losses of 10% and in the secondary line 5% respect the peak load.

4.2.1 Main line

In main line are positioned 8 branch points each one call with a letter from A to G. For every points are individuated the nearest building and calculate the power that everyone have to provide. Letter O indicates where the main line is connect with the boiler house, which is indicate with S. After point O, the line is immediately subdivided in two branches with opposite directions; the longer part is direct to N-W and the other to S-O. Eight segments of tubes are then designate and for everyone is calculated the power flow considering the difference of temperature between flow and return.

Length of every portition is measured and the best diameter is determinate with the explained criteria. When the difference of price between two configurations is very limited, the configuration chosen is the one that present a small diameter. This choice is taken because hydraulic losses are overestimate respect the normal condition, the flow is lower than in the project condition. This fact permit to reduce the thermal losses present during all the year, also in summertime, when the speed of water is very low and hydraulic continue losses in the tube are almost zero. An additional control is made on the hydraulic losses and speeds of water. The velocity is kept under 2 m/s and the max value presents is in the segment EO with design speed of 1, 84 m/s. Hydraulic losses in main line are included between 160 and 320 Pa/m, register in the S-O branch of the plant, shorter than the other. Every segment is indicated with the letter of the branch point that delimits it, AB, BC, CD, DE etc.

Figure 2: Curves of diameters optimisation



4.2.2 Secondary line

Secondary lines are designed to consider another criteria respect the real peak of power expected. These lines are project to arrive near every structure and the contemporary factor in a single building or in a small group result more evidence and for that reason is not consider the average consumption. For example, considering buildings with normal gas boiler for each flat, and an install power of 29 KW, is normal to think that the power is oversized but sometimes, (usually when the DHW is used) this power is necessary. Is no longer possible to consider the average demand of heat, but is preferable to consider that a part of install boiler could work at the same time with the max available power. For these reasons, local sections of tubes could be interest to a flow higher than in the average condition. Exceed the design flow in some section result more critical where there are little diameters in which is better to guarantee low velocity. In tubes with small diameter, little variation of velocity involve in great increase of losses. This criteria expected to use a different method to calculate the max power need for a restrict number of building. This problem is resolved considering that each interface units can absorbs a quantity of heat like the maximum installed power. The heat flow in the secondary line will be due to the total power connect in every branch point multiply for a contemporary factor. The value Chosen are the same using to HERA to dimension gas pipeline.

Table 23: Contemporary fact for gas Boiler proposes by Hera

Utilities number	Contemporaneity coefficient
1	1
2	0,75
3	0,6
4	0,65
5	0,55
6-9	0,5
10-14	0,45
15-29	0,4
30-49	0,35
50-99	0,3
100-199	0,2
>200	0,18

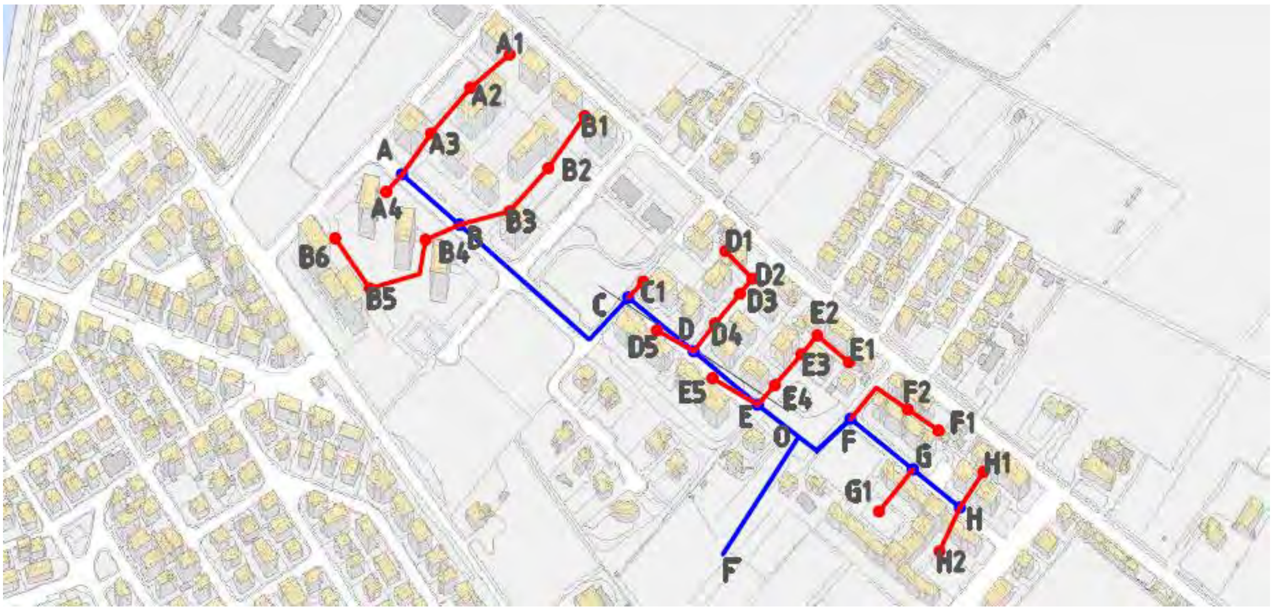
This method result more conservative, because the dimension of tubes is independent to the real peak of power for every flat but only calculating the possibly peak due to the high install power for every flat necessary for the DHW production. For the dimension of secondary lines is used the method of constant hydraulic losses for meter. The values chosen in the grid are different. In node A, B are taken values under 150 Pa/m because this building are more distant respect the boiler house and the diameter tend to be small. The other secondary line are designed with a losses under 250 Pa/m. Higher values of losses could be assumed, considering the available pressure present in the main line nodes, but this comport higher speed that aren't recommended . In the calculation of power with the method of contemporary factor is assumed that flat installs exchanger units with average power of 25KWh. This value is optioned consider the standard dimension of gas boiler installed in every flat and the minimum value to guarantee the DHW production. Less power may be install considering that sometimes in DH system there is a fix cost for every KW of power available and then the convenience to use storage system for DHW. In some situation, the value of power obtained is lower than the power calculated considering the real peak. In these situations, the higher value is taken.

For secondary lines has been evaluated some different solutions instead of rigid tubes and the possibility to used flexible pre-insulate tubes because, as said, result easy to install and cross the ground obstacles. Analyzing more in detail the solution present in the market result difficult using these tubes. PE tube, are usually produce only for PN6 and the recommended temperature is 80°C with the possibly to reach 95°C only for short period. Some constructors propose steel or copper flexible tubes but both present some disadvantage. Steel tubes have a wave structure and the high hydrodynamic losses and the recommended water velocities are about 0,5 m/s that increase the diameters, heat losses and the initial cost that result really remarkable. Copper tuber are produce only for small diameter, less than DN 32.

4.3 Grid configuration

The layout of the grid is visible in the map. Main line is colored in blue and secondary line in red. Secondary lines present many distribution points in which each buildings will be connected. In the map, all branches and distribution point are presents and each one is represented with a letter and number.

Figure 3: Grid layout



In the table 24 and 25 the dimension of tubes is show and length between two branch points.

Table 24: Tubes diameter in main line

Segment	Design power [KW]	Length [m]	DN
AB	480	65	80
BC	1579	194	100
CD	1643	69	100
DE	2283	68	125
EO	2846	41	125
OS	3910	100	150
OF	1064	59	80
FG	773	69	80
GH	532	52	65

Table 25: Tubes diameter in secondary line

Section	Number of flats connect	design power [KW]	Length [m]	contemporary factor	DN
A1-A2	66	606	43	0,35	65
A2-A3	119	625	52	0,2	65
A3-A	175	919	44	0,2	80
A-A4	31	285	20	0,35	50
B1-B2	35	322	43	0,35	50

B2-B3	70	551	50	0,3	65
B3-B	105	551	54	0,2	65
B-B4	124	651	32	0,2	65
B4-B5	62	488	74	0,3	65
B5-B6	31	285	52	0,35	50
C1-C	9	118	19	0,5	32
D1-D2	17	168	34	0,4	40
D2-D3	32	299	17	0,35	50
D3-D4	33	429	30	0,35	50
D4-D	45	518	17	0,35	65
D-D5	23	252	36	0,4	50
E1-E2	3	97	34	0,65	32
E2-E3	14	293	27	0,45	50
E3-E4	30	465	35	0,35	50
E4-E	38	548	27	0,35	65
E-E5	24	252	36	0,4	40
F1-F2	1	26	32	1	25
F2-F	28	294	67	0,4	50
G1-G	28	294	46	0,4	50
H1-H	10	118	36	0,45	32
H-H2	27	284	41	0,4	50

4.4 Hydraulic assessment

After the choice of tubes are calculated the hydraulic losses for every segment. Fanning friction factor is calculated for every condition considering the hypothesis of smooth tubes and turbulence condition using the Blasius equation.

$$f = 0,316 * Re^{-0,25}$$

Where Re is the Number of Reynolds calculated considering the water propriety at the temperature of 75°C, average condition between flow and return. Using Darcy-Weisbach equation, the losses for meter of tubes are calculated in all the segment of the grid. Total losses for every segment are calculated multiply respectively losses for meter of length.

Table 26: Losses in main line (single tube)

	DN	Internal diameter [mm]	Water speed [m/s]	Re	Fanning friction factor	Loses for meter [Pa/m]	Overall losses [Pa]
AB	80	82,50	0,72	155.588	0,016	49	3.212
BC	100	107,10	1,40	394.112	0,013	114	22.237

CD	100	107,10	1,45	410.235	0,012	123	8.502
DE	125	132,50	1,32	460.656	0,012	79	5.392
EO	125	132,50	1,64	574.222	0,011	117	4.786
OS	150	160,30	1,54	652.106	0,011	82	8.234
OF	80	82,50	1,59	344.825	0,013	198	11.745
FG	80	82,50	1,15	250.660	0,014	113	7.785
GH	65	70,30	0,79	172.398	0,016	59	3.039

Table 27: Losses in secondary line (single tube)

	DN	**Internal diameter [mm]**	**Water speed [m/s]**	**Re**	**Fanning friction factor**	**Loses for meter [Pa/m]**	**Overall losses [Pa]**
A1-A2	65	70,10	1,25	231.207	0,014	160	6.872
A2-A3	65	70,10	1,29	238.213	0,014	169	8.735
A3-A	80	82,50	1,36	296.224	0,014	150	6.614
A-A4	50	54,30	0,98	140.196	0,016	144	2.914
B1-B2	50	42,77	1,11	158.286	0,016	178	7.606
B2-B3	65	49,64	1,14	210.188	0,015	136	6.739
B3-B	65	54,26	1,14	210.188	0,015	136	7.367
B-B4	65	31,76	1,34	248.222	0,014	182	5.768
B4-B5	65	73,92	1,01	186.167	0,015	110	8.115
B5-B6	50	52,02	0,98	140.196	0,016	144	7.481
C1-C	32	18,63	0,90	86.740	0,018	206	3.839
D1-D2	40	33,52	0,96	106.484	0,017	188	6.302
D2-D3	50	16,66	1,03	147.012	0,016	156	2.603
D3-D4	50	29,78	1,48	211.071	0,015	294	8.764
D4-D	65	16,66	1,07	197.444	0,015	122	2.027
D-D5	50	36,38	0,87	124.045	0,017	116	4.223
E1-E2	32	34,48	0,73	70.748	0,019	142	4.892
E2-E3	50	26,86	1,01	143.986	0,016	151	4.047
E3-E4	50	35,36	1,60	228.904	0,014	339	11.992
E4-E	65	26,86	1,13	209.039	0,015	134	3.612
E-E5	40	36,38	1,43	159.235	0,016	380	13.829
F1-F2	25	31,96	0,61	33.571	0,023	207	6.607
F2-F	50	67,12	1,01	144.719	0,016	152	10.203
G1-G	50	46,24	1,01	144.719	0,016	152	7.029
H1-H	32	36,38	0,90	86.740	0,018	206	7.496
H-H2	50	41,34	0,98	139.550	0,016	143	5.898

The pressure necessary to feed with the correct flow the utilities less favorite is now calculated. These utilities will be in the end of secondary line, distant form the boiler house. The buildings connect in B6 and A1 seem to have the research condition. The first building, and the other closed to its, are the higher and present 7 floors reaching the high of 24 meters while the structure connect in A1 is the more distant. The calculation of total losses in this point need other data and considerations, for this purpose is considered that:

- Every building need tubes that measure like half its perimeter to connect the nearest connection point and enter inside the construction with overall loses of 200Pa/m
- Pipe long with the building high is necessary to connect the utilities presence in the last floor. Dimension of these tubes is not calculated but are assumed losses of 200 Pa/m including concentrated losses along the tube.
- Concentrated losses in main and second tubes are estimated like 10% of total losses. This value is safety advantage considering the lower number of curves and other components like valves.
- The necessary drop of pressure in exchange units is consider 1 Bar as required form some constructer

With these considerations is calculated the drop of pressure in the buildings connect in B6 and A1. Result useful to remember that the losses must be calculated for the flow and return tubes that present the same configuration.

Table 28: Losses of pressure along the tubes

	A1	*B6*
Main line losses [KPa]	104	98
Secondary line losses [KPa]	44,4	42,7
Concentrate losses [KPa]	25,4	24,5
Connecting pipes [m]	36	40,5
Building high [m]	18,1	24,4
Connecting pipes losses [KPa]	10,8	12,9
units exchange [KPa]	100	100
Total losses [KPa]	300	318

Pressure losses result very similar in the two situation and the critical condition has a value of 318 Kpa

4.4.1 Static pressure

An important aspect to consider is the presence of difference altitude between boiler house and the building or only in the zone occupied by bindings. Using Google Maps tools to measure the altitude in the area result that the difference is very limited and is possible to consider that all buildings are at the same high (less than 2 meters). The high of buildings is not treasurable and represent an important factor to calculate the pressure present in tubes. The higher constructions are connected in B6. In the top of this building is consider a minimal pressure of 0,5 bar to avoid problem with the formation of vapor. The minimum value of static pressure is then:

$$P_S = 50.000 + 24 * 9800 = 2.85\ Bar$$

The maximal pressure presents in tubes is then:

$$P_T = P_s + P_L = 2{,}8 + 3{,}18 = 5{,}98\ Bar$$

4.5 Thermal losses

Thermal losses depends first of all to the quality of the insulation layer present in tubes. The second factor is the ground typology. Insulation capacity of ground depends from many factors like the presence of water or type of soil. In our situation the limited dimension of tubes need a restrict depth of excavation, higher respect the level of garages or building cellars. That exclude the presence of groundwater in this area at this depth. The value of thermal conductivity used is 1,2 W/m*K and considering a deep of buried of 600mm for the upper part of the tubes. Air temperature is consider 13,4 °C, the yearly average in Verona.

The suggest method is reported in EN 13941 and required to calculate the thermal resistance of ground. Resistance is evaluate considering a shape factor that consider the depth of buried:

$$S = \frac{2 * \pi}{\ln(4 * h/D)}$$

Where:

h: tube deep measure from the center

D: external diameter of PHED tube

Equation is valid with the hypothesis of length L >> D and h>1,5D that are respected. Ground resistance can be calculated like:

$$R_G = \frac{1}{ʎ_g * S} \;\; [m * K/W]$$

Remember the equation for the calculation of the thermal resistance of insulate layer the overall resistance is:

$$R_{tot} = R_T + R_G$$

Thermal losses for meter of tubes result consider that the line work all year at the design temperature of 90-60 °C beside with an average value of 75°C

$$q = \frac{T_W - T_A}{R_{tot}} = \frac{75 - 13,4}{R_{tot}} \;\; [\frac{W}{m}]$$

The values are calculated for the utilized diameter and are show in the table.

Table 29: Thermal losses for meter of tube

DN	External diameter [mm]	Losses [W/m]
25	110	6,66
32	110	9,79
40	125	10,05
50	140	11,36
65	160	12,95
80	180	13,75
100	225	14,43
125	250	16,67
150	280	18,66

With these values are calculated the thermal losses in main and secondary line for every segment. Total thermal losses disperse a power of 22,1 KW.

Table 30: Thermal losses in main line (single tube)

	Losses [W/m]	Power [W]	Yearly energy [KWh]
AB	13,76	898	7.867
BC	14,44	2.807	24.585
CD	14,44	1.000	8.762
DE	14,44	981	8.590
EO	14,44	592	5.185
OS	18,67	1.867	16.353
OF	13,76	816	7.146
FG	13,76	945	8.277
GH	12,95	668	5.856
Tot	/	10.573	92.621

Table 31: Thermal losses in secondary line (single tube)

	Losses [W/m]	Power [W]	Yearly energy [KWh]
A1-A2	12,95	555	4.860
A2-A3	12,95	669	5.863
A3-A	13,76	608	5.327
A-A4	11,37	230	2.018
B1-B2	11,37	486	4.259
B2-B3	12,95	643	5.632
B3-B	12,95	703	6.156
B-B4	12,95	411	3.603
B4-B5	12,95	957	8.386
B5-B6	11,37	591	5.180
C1-C	9,79	182	1.598
D1-D2	10,01	335	2.938
D2-D3	11,37	189	1.659
D3-D4	11,37	339	2.966
D4-D	12,95	216	1.890
D-D5	11,37	414	3.623
E1-E2	9,79	338	2.957
E2-E3	11,37	305	2.675
E3-E4	11,37	402	3.521
E4-E	12,95	348	3.047
E-E5	10,01	364	3.189

F1-F2	6,67	213	1.867
F2-F	11,37	763	6.684
G1-G	11,37	526	4.605
H1-H	9,79	356	3.121
H-H2	11,37	470	4.117
tot		11.614	101.742

Yearly energy is obtained multiply the power for the value of 8760 h/year. In main line the losses are 185,2 MWh and represents the 4,2% of the carried energy. In secondary line losses are 203,4MWh and represent the 4,6 percent of total energy. Overall losses are 387 MWh/year. Considering only the summer period when only DHW is necessary, losses are the half of this value and represent in main and second line about the 30% of the thermal produce in the boiler house. Realty this value is lower in summer time because the outside temperature is higher and losses for meter are reduced. Otherwise may be possible to decrease the flow temperature.

Other losses are present in tubes which connect secondary line and every building but these losses hasn't been calculated because the connection with every building is hardly predictable. Length and diameter of every tube depend to the disposition of flat in the building and the number of tubes that cross the building.

5. Boiler house

5.1 Straw boiler and feeding system

There are two different way to use straw; directly o after palletisation. Direct use present many variants that depend first to the plant dimension. Straw ball can use directly to feed the boiler and this process appends in different way. In small plant balls are used one by one in a discontinue combustion process. In other case, automatic system can feed the boiler and there are two main solutions. Straw can be chaffed and put in the boiler with system similar to wood chip or use entire balls. The possibility to convert straw in pellet make the transport and storage easier. Palletisation can be made before arriving in combustion plant and permit to reduce the volume and increase the density and decreasing the transport cost. Moreover, palletisation represent an expensive process.

Considering the utilisation of straw without palletisation moving grate system, represent the technology that permit to obtain the best performance.

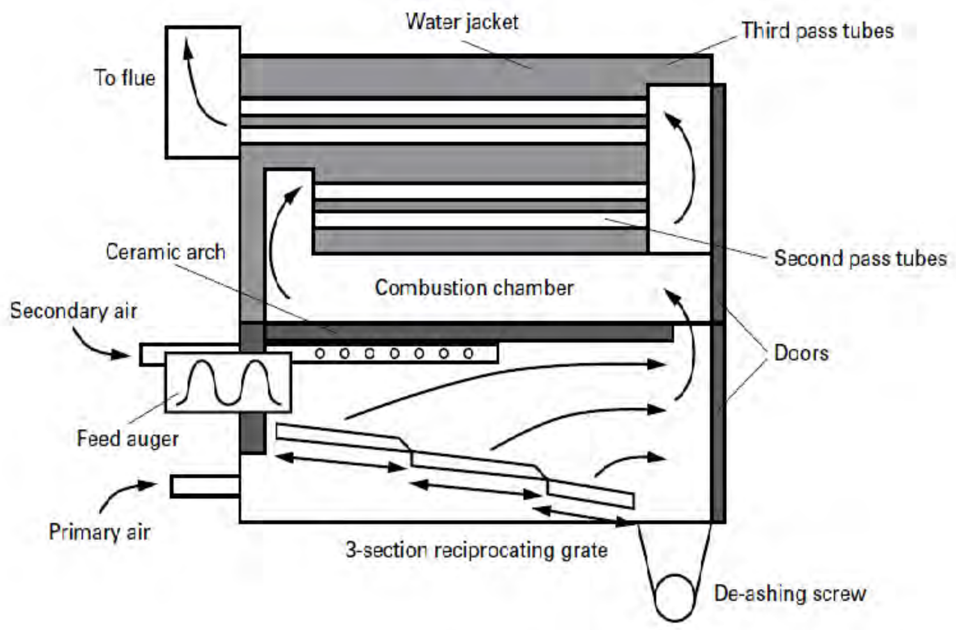
5.1.1 Moving grate system

Moving grate, also known as step-grate or inclined grate, is the most versatile systems in terms of flexibility of fuel tolerance. The large combustion space required an additional equipment, particular hydraulic system, involved often make them more expensive than other types.

Fuel is delivered into a series of inclined flat panels, which move in a sequence so the fuel travels slowly down the grate crossing all the combustion chamber. The fuel dries and combusts while it moves down the grate while primary air is supplied under the grate. Gases are emitted, and the matters burns out. This sequenced combustion is one of the great strengths of the design: changing the grate speed, fuel feed and air supply, it is possible to burn a wide range of fuels of varying humidity content. The presence of a ceramic arch over the grate reflects heat back, drying is improved and subsequent ignition, and thus permits the combustion of wet fuels with maximum value of 60% moisture content.

After the biomass has combusted, the remaining ash falls off the lower end of the grate, and is removed mechanically into the ash pan. Moving grate plants are popular in Northern Europe and Scandinavia where unseasoned softwood is commonly used for fuel. Generally, the minimal power is from 300 KW. These systems is usually feed with low quality biomass, pellet is then exclude from this category.

Figure 4: Moving grate boiler



Advantages:

- Wide tolerance of fuel type, high humidity content, and different size
- As a result of wide fuel tolerance, cheaper fuel may be used, helping to pay back higher initial cost.
- The movement of fuel down grate avoids the formation of blocks
- Well-regimented combustion leads an higher efficiency

Disadvantages:

- Relatively large fuel quantity in the plant leads to a slow response in the changing of power, although modulating controls improve controllability
- Large amounts of reflective refractory material using for wet wood plants can have in a long warm-up time from very low to full-load, up to 2 hours.

- Prolonged low-load mode operation can result in higher maintenance costs and reduced efficiency as a result of tarring of heat exchangers and condensing gases.
- More complex design and bulky components can lead to higher capital costs

5.1.2 Feeding system

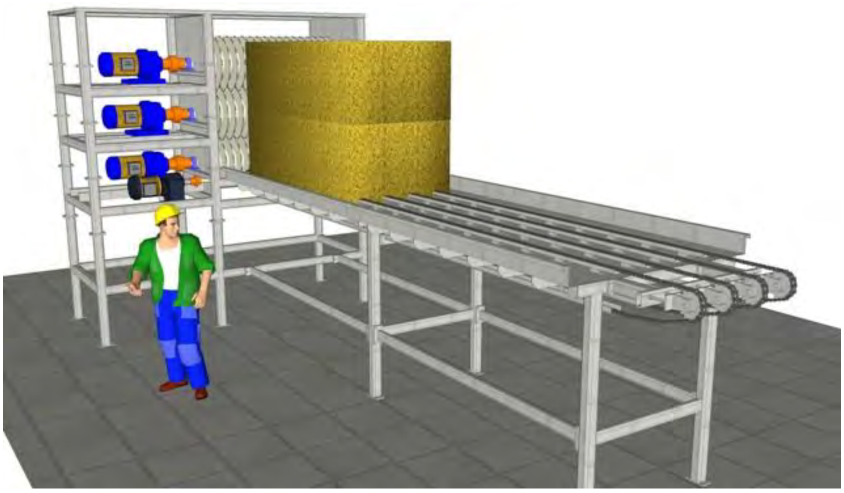
Automatic boiler have a mechanical fiddling system. This system is composed with an intermediate tank with reduction dimension that is filled continually. It is connect with the boiler and the large storage tank. The configuration in the case of chips or pellet are similar. Pellet is transport usually easily because it has more capacity of scrolling and the bottom of the big tanker where it is storage needs a less inclination. Transport can be made with argues or other system like big wheel urge positioned in the bottom of the tank or system with rakes.

Straw needs a different solution because to make the transport easy it is backed in bales. This solution is preferable because permit to reduce the volumes and increase the matter transport with a truck. Bales can be burned entire in the boiler with a big combustion chamber in relation to the boiler power, the case of batch-fired system. These boilers are usually feed with round bales with great dimension. Bales are move with front loader, take in the storage room and put directly in the boiler. These boilers present a big frontal tailgate large as the combustion chamber to put bales larger as possible. The opening and closing of tailgate is manually and the boiler work like a batch fired system with straw supply maximum few times a day. Heat is released in discontinuous way and it behaviour need big storage tank to absorbed the high pick of power.

Automatic boiler present more complicate system but can work completely alone for long period as chips of pellet system. The power of these systems is usually high, more than 500 KW until power more than 10 MW for steam boiler. Boiler configurator is similar to chips or pellet system and present argue that feed the combustion chamber. Differences are present in system that supply argue because straw boiler can’t storage in tank or other system common use for other biomass type. The common solution is to use a straw shedding line.

Straw shredding line consists of the following two main units: a table for feeding compressed straw balls and a shredder. The lines can break up straws of cereals or other energy plants delivered in form of compressed cubes.
The shredder contains shredding drums that contains cutting and shredding blades. Straw is broken up by the drums and falls to a charging hopper located at the bottom of the device that connect the shredder with the conveyor belt.
The shredding drums are driven by electric motors via multi-stage moto reducers. Changing the linear speed of the feeding table changes the performance of the whole line, the quantity of fuel broken up per time unit. The speed of the table is controlled with signals sent by the control cabinet of the boiler.
The length of the conveyor belt is usually relevant and cross the storage room. The length is important to establish the system autonomy because bales are load on the table with frontal loader or in larger plant with travelling cranes. When frontal loader are used is convenient to position the table in one side of the room to guarantee much space of manoeuvre for frontal loader. This is not a problem for travelling cranes that can move in two perpendicular direction reaching every point in the warehouse building. The table can be placing in the middle of the warehouse reducing the distant between storage fuel and table. Number of bales presents on the table when it is busy, establish the autonomy of the system.

Figure 5: Shredding line



5.2 The boiler sizing

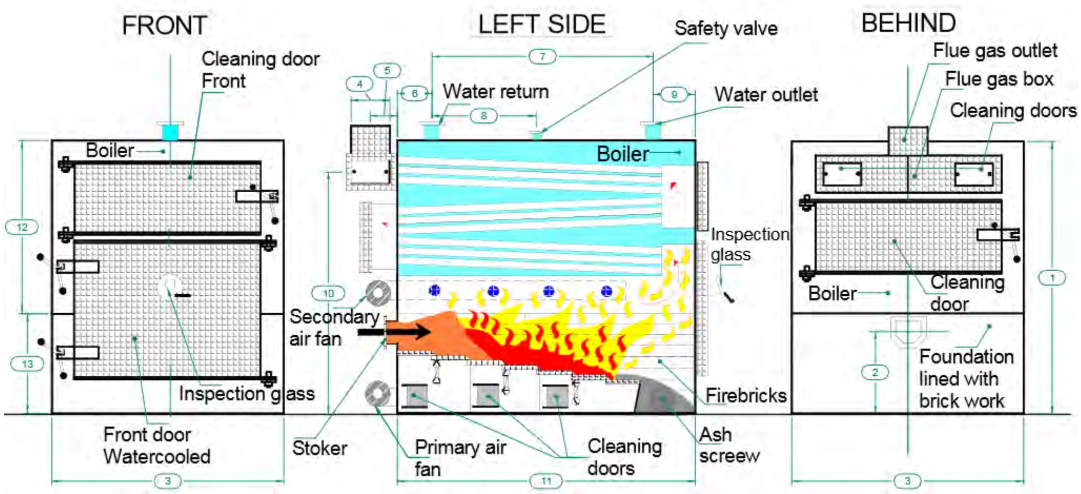
5.2.1 Straw boiler

The boiler chose for this plant is a biomass boiler design specifically to burn straw. The model that is analysed is produced by REKA, model HKRST and it is produced in a range of power between 100-3500KW. It is moving grate system moreover the company recommended to use dry matter with maximum 30% of moisture. REKA produce also the complete system need to feed this kind of boiler complete with table and shredder. The boiler present four passes of smoke and 3 of this are convention passes. The manufacture declare a life cycle of 20 years. Dimension data and boiler draw are here show.

Table 32: datasheet of REKA straw boilers

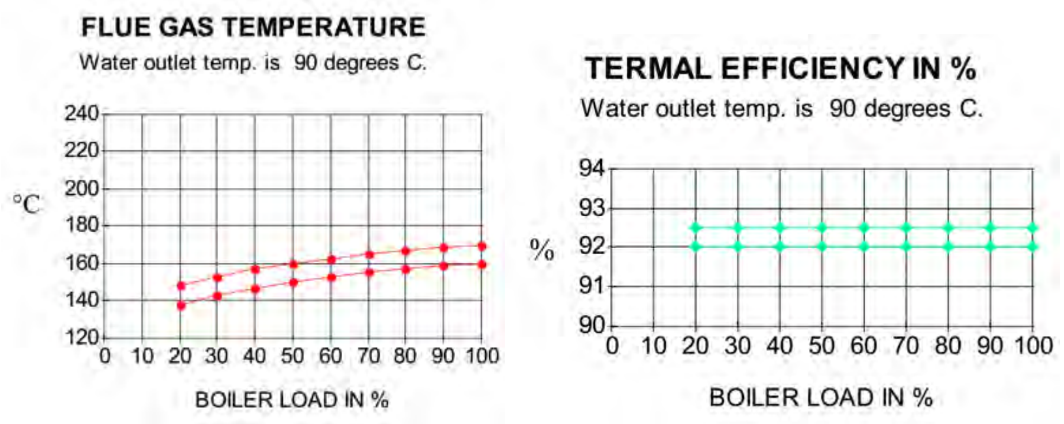
Boiler sizes kW	100	160	200	300	350	400	500	600	650	750	1000	1300	1500	2000
1. (Total height incl. Insul.) mm	1900	2050	1970	2400	2240	2420	2350	2420	2420	2780	2800	3210	3410	3655
2. (Floor to stoker) mm	800	880	900	930	930	930	950	1010	1010	1120	1150	1150	1150	1450
3. (Total. width) mm	990	930	1236	1316	1316	1370	1534	1534	1546	1534	1534	1722	1722	2340
4. (Flue gas duct diam.) mm	215	215	215	250	250	250	250	300	300	300	300	350	350	590*590
5. (Flue gas box to boiler) mm	250	270	250	240	240	240	240	240	240	350	300	320	320	600
6. (Back end to flange) mm	320	320	400	330	400	370	538	390	390	515	730	730	730	1680
7. (Between outl.- retu. fl.) mm	950	1400	1500	1370	1300	1440	1344	1600	1600	1970	1805	2000	2000	2250
8. (Between safty - retu. fl.) mm	360	600	750	680	650	690	672	800	800	1045	970	1000	1000	1130
9. (Front end to outl. flange) mm	240	550	400	570	570	460	734	630	630	795	730	720	720	600
10.(Floor to flue gas box) mm	1675	1820	1800	2100	2065	2150	2120	2270	2270	2515	2550	2920	3120	2970
11.(Total length) mm	1770	2515	2300	2520	2520	2520	2780	2780	2900	3528	3530	3700	3700	4530
12. (Boiler height) mm	1270	1300	1270	1646	1546	1670	1610	1610	1610	1850	1850	2260	2460	2455
13. (Foundation height) mm	625	750	750	750	750	750	750	810	810	930	950	950	950	1200
Stoker screw diameter mm	150	150	180	180	180	180	180	200	200	250	250	250	250	300
Ash screw diameter mm	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Outlet flange (PN 16) mm	50	50	65	65	80	80	100	100	100	100	125	150	150	200
Return flange (PN 16) mm	50	50	65	65	80	80	100	100	100	100	125	150	150	200
Safety valve flange (PN 16) mm	32	32	40	40	40	40	40	40	40	40	50	50	50	125
Boiler weight without water kg	1500	1800	1900	2100	2300	2400	3300	3600	3800	4000	5800	7000	7700	10200
Foundation section weight kg	1000	1200	1200	1600	1600	1600	2500	3000	3000	3500	3700	5000	5000	6000
Water content litre	1000	1150	1250	1400	1600	1800	2300	2600	2900	3100	5200	5000	5600	10500
Hydraulic test pressure bar	5,2	5,2	5,2	5,2	5,2	5,2	5,2	5,2	5,2	5,2	5,2	5,2	5,2	5,2
Design pressure max bar	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5
Turning radius frontal door mm	550	700	700	800	800	800	1000	1150	1150	1100	1100	1150	1150	1150

Figure 6: Straw boiler scheme



The efficiently of this boiler is declared by REKA and it is constant in the work range between 20-100% of nominal power and the declare value is include in a band from 92 to 92, 5%. The flue gas temperature instead increase with the boiler load.

Figure 7: Outlet gas temperature and thermal efficiency



Boilers feed by fossil fuels (in particular natural gas) have the capacity to modulate the heat production to handle different thermal load during the day. They are able to follow the heat profile of user. These boilers are often oversized because they can handle the peak of demand and cover always the overall heat load. Appling this method at the biomass boilers there would be a lot of problems because these systems are less reactive and ready to handle a change of load causing continue switch on/off. The disadvantages derive to this behaviour are innumerable and can decrease the seasonal efficiently until 50% due to the long-time need to reach a good level of combustion after every restarting. The main problem are:

- Low combustion quality
- Low efficiently combustion
- Increase of dangerous emission
- Major component wear
- General problem to the system

To prevent these problems is necessary to distinguish in the design phase the average and the picks load. The ideas of this approach is to design the boilers so that they are able to satisfy only a part of the pick load. Normally, biomass boilers should not work under a load of 30% and 25% for pellet boilers that involve in a continuous switch on/off.

A common solution is to use a boiler that cover only 55-65% of the peak. In this way, the boiler will work for a lot of time in a power range includes between 50-100% respect its max power. This solution is which usually minimising the initial cost and increase environmental benefit. Not-cover load must be supply to another boilers usually feeds by fossil fuels that present lower installation cost.

Another important aspect, which is closely linked with the boiler dimension, is the necessity to use buffer vessel. Whit tanks is possible to exploit better the boiler power. Two different situation can be study in which heat storage can create vantages. A first situation in when the boiler have to handle a demand major than the biomass power. In this case, if the peak have a short duration is possible to storage heat in the buffer vessel and use it during the pick. In second case, the tank is useful to separate the production and heat consumption. For example, if the load is low, under the boiler modulation capacity the storage admit to produce heat with an high rate respect the current demand and use that heat when the boiler is switch off. Whit this solution is possible to reduce the number of switch on/off for hour or day and increase the load cover with an undersized boiler because the inertia of the system is increased.

Vessel tank are usually made in steel cover with an insulant layer of polyurethane foam with a thickness that can exceed 30 cm. Other the scope to increase the boiler efficient increasing the time in which it work at full load or reducing the number of switch on/off, vessel tank can be used to control the system using temperature probe and variable speed pump. Inside tank, the water creates layer with different temperature using a correct connection with boiler and plant. Easier system present only two probe in the top and bottom but more complex can have more than 5 thermostat that monitoring the quantity of energy present in the tank and control the boiler functioning. The dimension of required tank depends to the boiler typology but usually is included between 10 l/KW to 40 l/KW in batch-fired system. The chosen boiler is the type “walking floor burners” and present a high capacity to modulate the power until 20%. A tank with a volume of 15m^3 is taken.

5.2.2 Integration and reserve boilers

The dimension of boiler is made using a commercial software with whom run some simulation. Before the choice of biomass boiler is dimensioned tank and the gas boiler.

To calculate the dimension of integrator boiler is observed the peak load in critical day. That is infect necessary to cover the entire energy demand in the coldest day. A possible and good solution, often adopt, is to use more than one boilers increasing the system reliability. The possible solutions are different, for example using boiler with different or equal dimension end also the number of boiler depend to designer volunteer. In this case is decide to adopt two boilers with two different dimension. One with a power of about 1000 KW to cover the normal heat demand and another with 2000 KW that can be used in the coldest day instead the other gas boiler or in case the failure of biomass boiler. The chosen model have respectively net power of 1020 and 2000 with an efficient of 92,22% and 92,29%. This solution respect the rule (1/3 + 2/3) frequently use for the boilers dimension. The two boilers adopt RIELLO burner with two modulating stage. Gas boiler number 1 with nominal power of 1020 KW uses the model 7/PM with power of 400-1760 KW. Gas boiler 2 uses the model 8/PM with power 640-2210 KW. The type of burner decide then the minimal output power.

5.3 Simulations with a commercial software

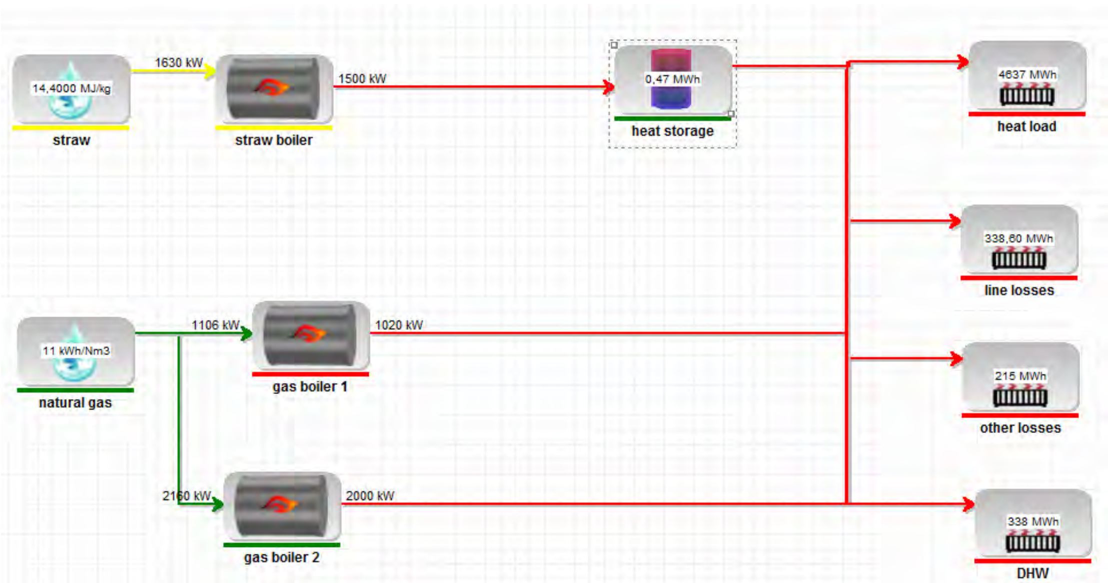
This model is realised to analyse and choose the straw boiler size and after calculate the yearly consumption of the system.

The fuels use in the model are straw and natural gas. Straw is define insert the heat capacity for kilogram of wet matter. In the table 14 is reported the value of 14,4 MJ/Kg for straw with humidity continent between 10-20%. Natural gas is declare with 34,5 MJ/Nm3

In the model are implemented all boilers, straw and biomass with the purpose to choice a good solution. The software Energy Pro permit to insert how much boilers you want and decide the priority in their use. Straw boiler have the absolutely priority, while the gas boiler are used like reserve and have net power respectively of 1020KW and 2000KW.

Tank storage is created with volumes of 15 m^3 with an utilisation efficient of 90% to consider the layer of water present in the top and bottom that usually don't attend in the storage process. The model includes also thermal losses calculate consider the surface and the insulation layer with a thickens of 30 cm and λ = 0,036 W/m*K. In this simulation, only biomass boilers are allowed to storage energy. The storage temperature change from 60 to 90°C and in this condition the thermal capacity is about 0,47 MWh.

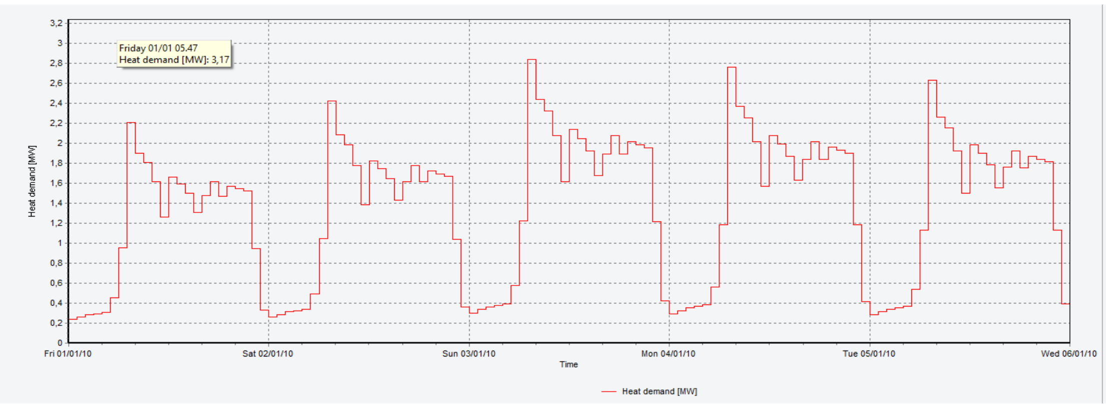
Figure 8: Schematic representation in the software



Heat load is divided in 4 different component.

- Winter heat load: is present only in heating period from 15/10 to 15/4. It includes the energy for heating and for DHW presents in these months. For heating the energy is 4400MWh and for DHW consider only half of year value 339,5 MWh. The program divides this value for every single day consider two constrain. The first is the daily trend established in the chapter 3 and the second considers the real temperatures distribution refer to 2010. Program calculates the daily energy divides the seasonal value in relations to the single day temperature and after divided this amount consider the hour distribution. The trend of consumption is the same in every day, but the maximum values change and homothetic curves are obtained.

Figure 9: Daily trend of demand



- Summer load: in this period only the DHW consumption is present. The overall energy is equal to 339,5 MWh. Every day presents the same consumption and the program divide this values for the number of days include between 15/4 and 15/10. Daily distribution have a trend hypnotised in the chapter 3 for DHW.
- Pipes losses, are the losses present in main and secondary line. This values has been calculated and equal to 388,6 MWh. Its distribution depend to the difference between the air and average water temperature of 75°C calculated in every hour and in every day of the year.
- Other losses are considered constant during the year and the overall values is 5% of the yearly energy. These losses are all the thermal losses not yet consider and for example present inside boiler house or in the pipe that connect secondary line with flat unit.

As said the model is resolve consider that straw boiler have the absolutely priority for obviously reason. Five different dimension of straw boilers are evaluated considering the model produced from REKA, respectively: 650, 750, 1000, 1300, and 2000 KW.

5.3.1 Result

For every one of the mentioned boilers are calculated the part of load that everyone can cover and this value is related to the total heat including losses, the yearly operation time in full and partial load and the number of turn on/off in the season.

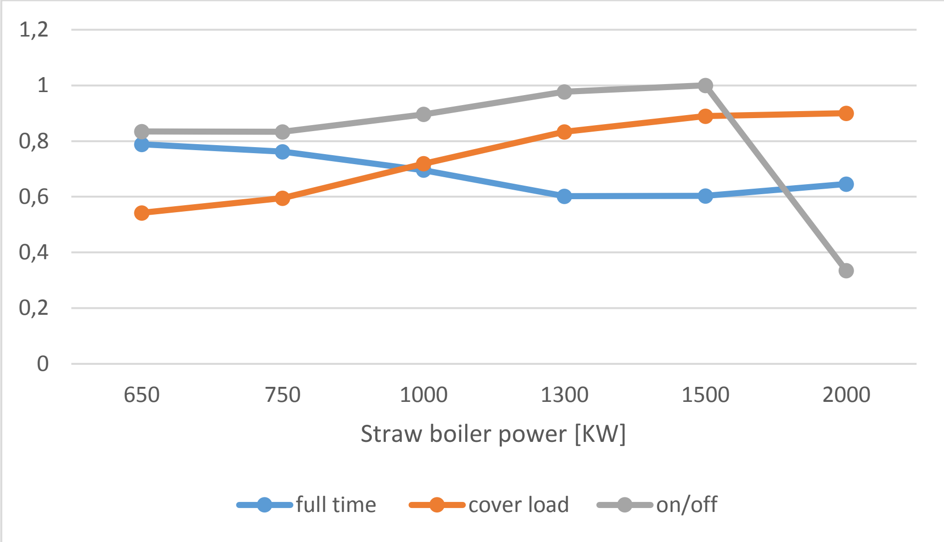
Table 33: Result of simulation with different boilers

Model	650	750	1000	1300	1500	2000
Load [KWh]	5529	5529	5529	5529	5529	5529
Supply energy [KWh]	2999	3289	3975	4607	4919	4975
percent of cover load	54,2	59,5	71,9	83,3	89,0	90,0
time of work[h]	5858	5774	5713	5886	5438	3854
full time work [h]	4618	4399	3976	3544	3280	2488
Full time work percent	78,8	76,2	69,6	60,2	60,3	64,6
Number on/off	656	655	704	768	786	263
On/off percent	83,5	83,3	89,6	97,7	100,0	33,5

Percent value of on/off is obtain in relation to the maximal value register with these boilers.

For the 2000 KW boiler the number of on/off is lower because in summer time it does not work because load is too low for this boiler. Percent value are reported in the follow graphic.

Figure 10: Percent value refers to the boiler dimension



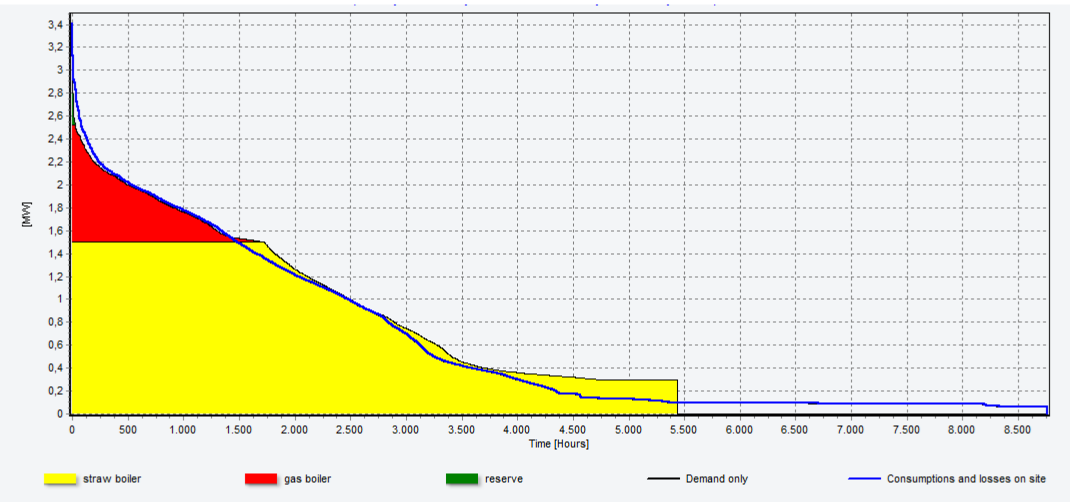
Boiler with a dimension of 1000KW cover just the 71% of the load and is not considerate acceptable. Boiler with the dimension of 2000KW result instead oversized and can hardly used in summertime for DHW production without consider a larger storage tank. A good solution using only one biomass boiler and without subdivide the power in more boilers seem a boiler with 1300 or 1500 KW. For this, two-solution the work hours at full load are almost the same and the number of switch on/off that are due in principal way to the summer load. In winter time this two boiler can work continually without stop (excluding maintenance stop) as show in the table:

Figure 11: Number of stitch on/off for 1300 and 1500 Boilers

Boiler	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1300	768	0	0	17	76	118	111	114	114	113	73	32	0
1500	786	0	6	31	78	114	108	106	109	110	82	39	3

The behaviour of two boilers is very similar during the year. For these reason is chosen the solution that permit to cover great part of yearly load and it is represented from the bigger of the two. Yearly behaviour for 1500 KW boiler is shown in the duration diagram.

Figure 12: Duration diagram for the 1500 KW boiler



The analysis provide the yearly consumption of fuels for straw and natural gas and function date relatively at every boiler. Total energy producted is 5529 MWh, with a max peak of 3,2 MWh. The reparation for every boiler is report in the table.

Table 34: Boiler yearly dates

	Supply energy [MWh/year]	**Working time [Hours/year]**	**Working time at max power [Hour/3day]**	**Fuels consumption**
Straw boiler	4918	5436	3279	1338 tons
Gas boiler 1	609	1710	599	68740Nm3
Gas boiler 2	4	31	1	390 Nm3
Total	5531	7177	3879	/

Monthly straw burned is report in table 35. These values are important to know the flow of straw during the year and design the storage system and organised the delivery system.

Table 35: Monthly consumption of straw

	J	F	M	A	M	J	J	O	S	O	N	D
Monthly demand [MWh]	108 5	883	814	350	74	69	70	71	71	340	631	1071
Monthly straw energy [MWh]	887	775	745	348	73	68	69	70	70	339	605	869
Consumption [Tons/month]	241	211	203	95	20	19	19	19	19	92	165	236

5.3.3 Pumping energy

EnergyPro does not provide pumping energy for the grid but is possible to estimate them using the duration diagram. Volume of water that circulates in the pipeline is proportional to the provide heat consider also the losses in the grid. Volume of water move in the tubes is calculate consider the hourly provide energy with 30°C of difference of temperature between flow and return. In this way is possible to know for every hour of the year the water flux in the plant. Pressure drop in the pipeline has been calculated and is equal to 3,18 bar for the disadvantages user. This value do not consider the drop of pressure present in the boiler house exchange that can be consider equal to 1 Bar. Another 1,5 bar can estimate like the losses present in the other side of exchange and in the boiler and internal pipe. Drop of pressure are calculate for the project flow but usually system works in partialisation and design condition are reached for few hour a year. Drop of pressure are normally lower and value tend to zero with almost nothing flow. Pumping system can follow the reduction of losses when flow is lower reducing the pump head. It necessary to guarantee a minimal pressure also when flow is almost zero to guarantee the correct function of flat units. Losses with null flow are then consider 2 Bar in the pipeline and 0,5 inside boiler house. Variation of head is from 2,5 bar to 5,68 Bar with a linear trend between middle value.

$$P = 0{,}193 * Q + 2{,}5$$

P = pressure [Bar]

Q = flow [l/s]

Efficient of pump is consider 0,7. Total energy use for pumping result 29080 KWh/year.

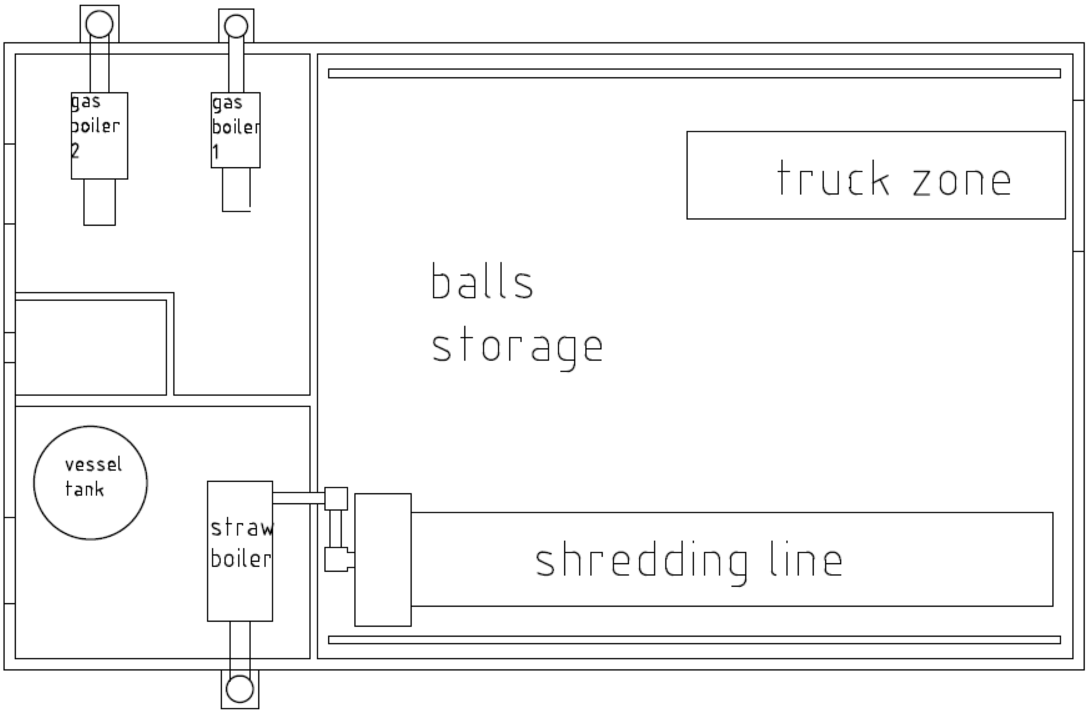
5.3.4 Fuel storage system

In the plants present in North-Europe fuel storage system are usually limited and contain fuels for a short period like 1-2 weeks. Straw is always storage during the year in farm and transport with truck in the short-term storage present in boiler house. As verify in chapter 3, straw is produce in great quantity nearby the DH plant and for this reason the possibility to install only a short-term storage is consider sufficient. Autonomy of 7 days is consider in the month with higher consumption that is noticed in January. Consumption is like 240 Tons of straw. Round baler common in north-Italy present a density of 110 Kg/m^3 with an average weight of 250 Kg, 150 cm of diameter and 120 cm of width. Balls are consider stack up in column composed with four lay on the round side on the floor. Column high with 4 balls are then 4,8 meters and packing factor due to the round shape is about 78%. Plant area for these condition and for guarantee a reserve for 7 day is 140 m^2.

5.3.5 Boiler autonomy

The boiler autonomy depends to the number of bales present on the straw shredding line. Number of bales depend to the length and this last depend to the dimension of straw storage. Building that contain storage is crossed by shredding line. Length of 18 meter is considered because building have to include an area of 140 for balls and space for truck that transport bales. Using bridge crane to unload and move balls in the storage in necessary that the truck enter in the building storage. Consider a max consumption of 1,5 bales hour and the previous consider dimension, boiler can have an autonomy of 10 hours sufficient to guarantee the correct function during the night.

Figure 13: Boiler house configuration



6. Evaluation of alternative solutions

Purpose of this part is to study some alternative solutions to compare with DH and the existent situation, which may involve in economical or environmental benefits. Two alternatives are evaluated both with renewable energy system. The first is a system with heat pump and the second with solar collectors. Both solution are thinking as a centralise system without DH connection and their behaviour is evaluated only for two building between the all present in the area. The reason of this choice is due to the necessity to kept down the flow temperature when you use heat pump and that result incompatible with DH. Minimal flow temperature must be almost 70-80°C and is not a good solution with heat pump that does not work with geothermal source. For the second solution, the idea to include solar collectors in parallel with biomass boiler and using a DH system, the idea has been refused because in summer time the losses of pipes are almost equal to the DHW consumption and the surface necessary to cover the entire production should be doubled with high cost of installation. In other case, the economical convenience would be really limited or inexistent because the cost for KWht with biomass system is really low and the initial cost for the plant can only grow. A said, the alternative solutions are analysed for two different constructions with different dimension and insulation and significant for the group of edifices chosen in this project. These buildings are the number 19 and 38 indicate in the initial map. The consumption in these buildings has been calculated in the previous chapter and heat load, peak of demand, DHW yearly energy are remembered in the table.

Table 36: Energy data for the buildings

Building	**19**	**38**
Heat load [KWh]	62.000	159.800
Peak [KW]	26,4	67,4
DHW yearly energy [KWh]	7.700	32.800

In this case, more attention need the production of DHW because the installed power are now reduced. An accurate evaluation of the maximal possible consumption of hot water and respectively duration result necessary. DHW water is produced for both configuration with centralise system as will be explain. For this purpose, the regulation UNI 9182 is adopted and all calculation are reported in Appendix A.

6.1 Heat pump system

Heat pump can produce heat with a part of renewable energy infect thermal energy present in the air, ground or water can be used like a heat sink and heat pump permits to increase the temperature of this energy. This process needs energy and the environmental convenience depends to the relation between the electric consumption and the heat produced. The easier solution, to avoid other works, is to use air evaporator heat pump although is the less performance but also present less initial cost. Air heat pump are able to adapt to the Verona wheatear condition and in wintertime, the environmental and economic convenience is usually present.

For district heating system has been designed a system that don't consider a climatic regulation and in every flat was possible to manage the heating working time how do you want and for this a great pick of demand in the morning was considered. In this second solution initial cost of heat pump, many times more expensive than biomass or gas boiler with equal power, asks to avoid peak in one part of the day and the necessity to increase the efficient recommend to work with the lower possible temperature. For example, in DH system supply water have a temperature of 90 °C and a reduction of this value does not comport significant changing of global efficiently. Climatic regulation results a good choice to keep down flow water temperature. DHW production can't longer produce separately but need a centralisation solution. Produce DHW separately in every flat need that the provide hot water have a minimal guarantee temperature and this is not possible with climatic regulation made directly from heat pump.

System is composed from heat pump with own tank storage and another tank for DHW production. Moreover a boiler is install in parallel to satisfy heat demand in the coldest day of the year when the COP is lower or when gas result economical convenient.

6.1.1 COP values and conveniences

The COP of heat pump change when outside temperature decrease sometimes more than 50% if the external temperature drop for example from 10 °C to -5°C considering a fix flow temperature. Moreover, using climatic regulation, when external temperature drop a higher flow temperature is necessary and the difference of temperature between evaporator and condenser increase and COP reduction is even more evident. Result useful to understand until which condition heat pump is convenient respect normal gas boiler. This convenience can be analyse considering two different aspect: environmental and economic but both depend to the drop of COP value.

Environmental factor considers the overall coefficient to transform primary energy in electric energy. It is necessary that heat pump produce a quantity of heat major that the value obtain with a simple combustion of fossil fuels. Value of conversion is defined from Energy Authority and its changes in function of the production method and it is periodically update. Electricity is overall consider producted using 0,187*10^-3 TOE/KW. Considering that one TOE is like 11,6 MWh coefficient that you are looking for is 0,46 . Necessary condition is that heat pump use less quantity of primary energy respect a normal boiler. This can be explain with the follow relation:

$$COP * \eta_{el} > \eta_B$$

η_{el}: Conversion coefficient between primary energy and electricity

η_B : Boiler efficiency

Boiler efficienct is in this case considers the value of the boiler that will be install in parallel with heat pump. The value considers the instant efficiencies because the purpose is to define the minimal convenient COP and do not define a seasonal convenience. The boiler that is consider is a normal gas boiler without fumes condensation and a reasonable value is about 95%. Minimal COP results:

$$COP > \frac{0,95}{0,46} = 2,06$$

Economical aspect consider also the price for electricity and natural gas to evaluate the convenience to use one or the other system. Price of electricity is considered 25€/MWh while the price of natural gas is 0,85 €/mc equal to 8,84 €/MWh.

$$COP > \frac{C_E}{\frac{C_{NG}}{\eta_B}} = \frac{25}{\frac{8,84}{0,95}} = 2,69$$

When COP drop down this limits heat pump is no longer convenient. Economic condition are more strictly then environmental condition and the choice of one or other method change radically the management of plant. Every value of COP is bound with a minimal external temperature and fix value of COP mean have an external temperature under that heat pump do not have to work. Calculating this temperature need to know the flow temperature. Result necessary to fix the trend of flow water in relation to the external temperature. It's hypnotize that terminal are represented by traditional radiator with a project temperature of 60 °C when outside temperature is -5°C. Minimal work temperature is fix in 30°C when outside temperature is 15°C. Linear correlation is consider between the two points. Correlation is express by the equation:

$$W_t = 60 - 1,5 * (T - 268)$$

T: external temperature in K

W_t: Water flow temperature

6.1.2 Plants configuration

Thermal power station is composed from heat pump, reserve gas boiler, storage vessel for DHW and another one with a small demission to increase the inertia of hydronic circuit. Dimension of boiler depends also to the system adopt for DHW. Peak duration has been fixed in two hours. Preheating time is normally pone in three hour. Flow temperature is consider 42°C and temperature in the tank 45°C. Tank temperature must be lower as possible because production happened with heat pump. Initial temperature is consider 12°C. The dimensions obtained with these conditions are report in the table.

Table 37: Require data for the DHW production

Building	**N°19**	**N°38**
Tank volume [l]	820	2650
Necessary power [KW]	9	29

Hot water is produced in a plate heat exchange outside tank because the level of temperature in the tank are critical and a correct stratification is necessary to guarantee a correct temperature, moreover this solution permit to exploit better the tank volume and accept a reduced jump of temperature between technique water provide from heat pump and DHW present in the tank. In these conditions different of temperature of 7°C is enough to avoid a larger area exchange. Temperature of 52°C is assumed provide from heat pump.

Building number 19

Heat pump is chosen to cover a lot of part of peak in wintertime. Maximum heating peak is 26,4 KW. With this machine result convenient the DHW production and an extra power of 9 KW is necessary consider a preparation time of 3 hours and a peak time duration of 2 hours. Moreover is necessary a storage vessel with a volume of almost 790l. The heat pump chosen is the smaller in the serial of AIRMAX HT 407 and it is the model 23T with a nominal heat power of 29,1 KW. The remaining part of load is covered by a normal gas boiler with dimension able to cover the entire power without consider heat pump. Gas boiler functions like an integration and reserve boiler. The model is TREGi 6N produce by Riello and its maximal power guarantee a safety coefficient to cover the maximal peak load. Dimension of tank for DHW production is kept 800 l consider the standard model. It is necessary a storage tank connect directly with the heat pump to decrease the number of switch on-off. Rossato groupe suggest that in the heating plant, a good water content is 10l/Kw of power for a heat pump that work with 5°C of temperature different. Consider the presence of tubes radiator the quantity of water content in the plant is more than the suggest value but a tank of 100 l is consider to guarantee a correct value of inertia in every circumstance.

Building number 37

In this circumstance has been noticed that is not convenient to produce hot water with heat pump(COP of this model is too low) and in winter heat pump have only to supply water for heating. Peak of demand is 67,4 KW and the heat pump chosen is AIRMAX HT 407 model 41T with a nominal power of 53,7 KW. Integrator boiler is the model RTN 3S N 166 produced by Riello. DHW is produced in heating seasonal by the gas boiler and in summer from heat pump. Dimension of storage vessel is calculate consider the minor available power in the two season. Gas boiler have a net power of 157,4 KW and also able to cover the entire heat load. Heat pump have a nominal power lower than the gas boiler and then for DHW production the critical period is in summer time when is necessary a tank with major dimension. Applying in inverse way the equation propose in UNI 9182 and consider always 2 hours of peak duration, one hour is enough for the preparation and is necessary a storage vessel of almost 1470l. Commercial dimension of 1500l is taken. Heat pump is connect directly with a storage of 200l

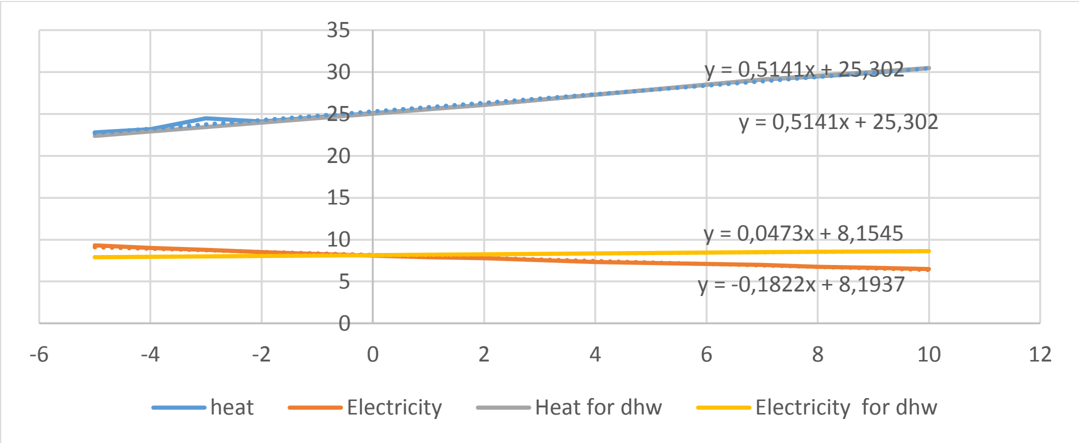
Table 38: Resume data of heat pump plant

Building	N°19	N°38
Peak load [KW]	35,4	96,4
Heat pump model	AIRMAX HT 407 23T	AIRMAX HT 407 41T
Nominal power [KW]	29,1	52,5
DHW tank [l]	800	1500
Heat pump tank [l]	100	200
Gas boiler	Riello TREGi 6N	Riello RTN 3S N 166
Nominal power [KW]	48,2	157,4
Efficiencies	90,7%	94,8%

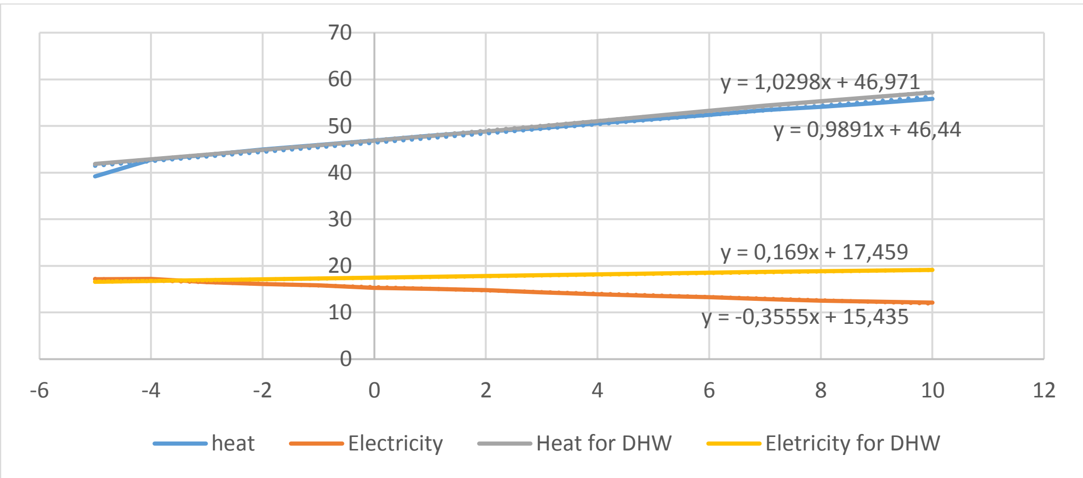
6.1.3 COP values in working conditions

During the year heat pump works with different level of temperature because the outside temperature changes and the flow temperature in according with climatic regulation is proportional to the external temperature. External temperature can be correlated with flow temperate. In this way is easier to calculate the yearly consumption of electricity. Work data are reported in the datasheet provide by Rossato Group for the flow temperature of 35, 40, 45, 50, 55, 60 and for some external temperature. Rossato group reports for every one of these conditions the heat produced and the energy consumption. These two value are interpolated for every temperature between -5 and 10 degree and relatively flow temperature. The result is a couple of values that define the COP in function to the external temperature. How could be imagined the heat production have a growing trend while the electric consumption decrease. Behaviour is report in the follow graphic. Working condition are also calculated for DHW production considering a fixed flow temperature of 52°C.

Graphic 6: Heat production and electric consumption for the model 23T

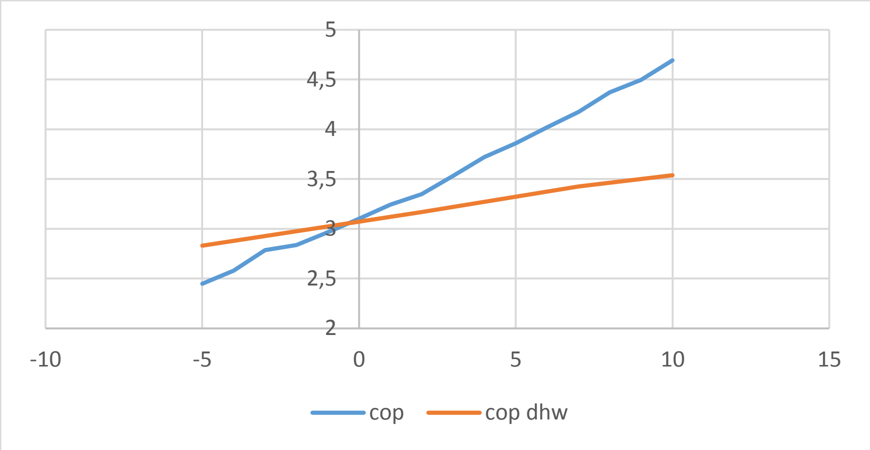


Graphic 7: Heat production and electric consumption for the model 41T

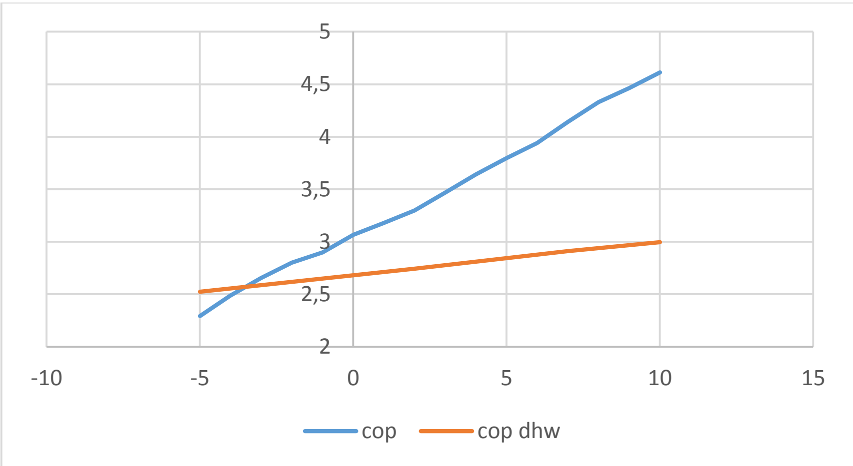


Trend are approximate with a linear function which expression is reported directly in the graphic number 7 and 8. COP is calculated for every condition making the division between the two values. These values are reported in the graphic 9 and 10 and is possible to notice the different behaviour between heating and DHW production. COP for DHW is higher with lower temperature because water for heating is produced at higher temperature while with an external higher temperature the situation is the opposite because the temperature of flow water drop.

Graphic 8: COP for the model 23T



Graphic 9: graphic for the model 41T



With model 23T for temperature major of 0°C COP is over 3 and then the utilisation of this machine result convenient for the both purpose, heating and DHW. In the second model, 41T situation is different and until 10°C, there is no economical convenience to use heat pump to produce hot water. These aspect was already considered in the initially dimension because these aspects resulted evidence from the data before interpolation.

6.1.4 System simulation

Heat pump performance are represented with the function obtain in relation to the external and water produced temperature. Model are divided in two-step, one for the heating seasonal and the second for the summer period, because heat pump work with two different curve when produce heat or when produce DHW. In winter time in the model for the building N°19 is assumed that DHW is produced with the same curve of heating. This is necessary because separating the two production in two different models would be lost the entire peak and heat pump will produce more energy than the possible value. This problem is not present in building 38 because in wintertime DHW is produced with the gas boiler. The loads are due to heat and DHW and both these consumptions are increase of 5% to consider the losses in the production room, storage and distribution pipes.

- Heat load, in according with the hypothesis of climatic regulation is proportional to the external temperature and heating system function only when outside temperature drop under 15°C. Yearly energy consumption is subdivided hour by hour proportionally to the different between external and the reference temperature of 15°C. (It is remember that whit external temperature of 15°C water is produce with a temperature of 30°C and the heat pump COP consider this.)
- DHW energy is equally divide for every day of the year. Daily trend is considered the same use for DH simulation in summertime. This trend comport a peak that have a half value compared to the maximal consumption calculated with UNI 9186.

Storage tank considers in the model is the only for the DHW production. Gas Boilers model not present particular problem and for both solution are implemented.

6.1.5 Result

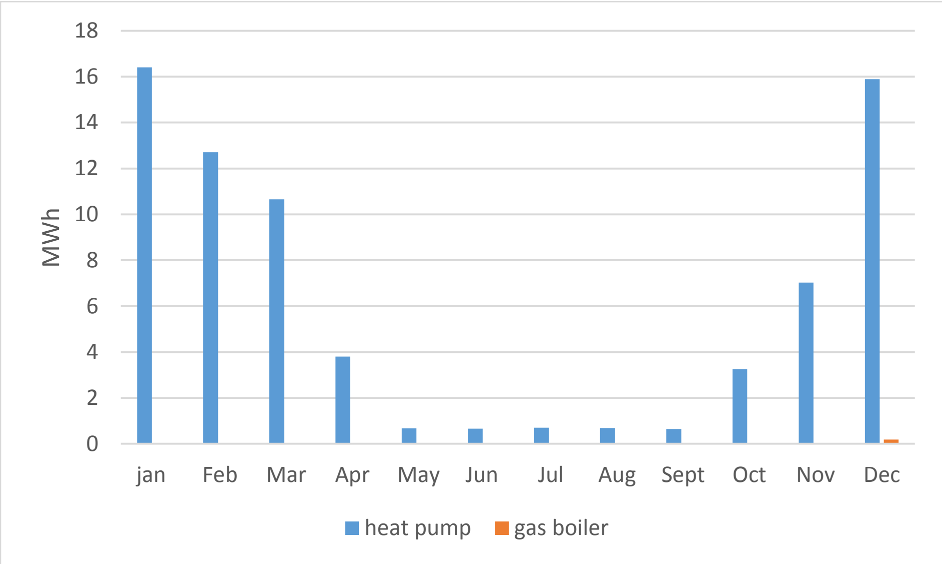
The fuel consumption for both buildings is represented from electricity and natural gas and is reports in the table. In building number 19 heat is produce almost completely with heat pump while in 38 in wintertime gas boiler cover until 15% of the demand.

Table 39: yearly consumption of gas and electricity

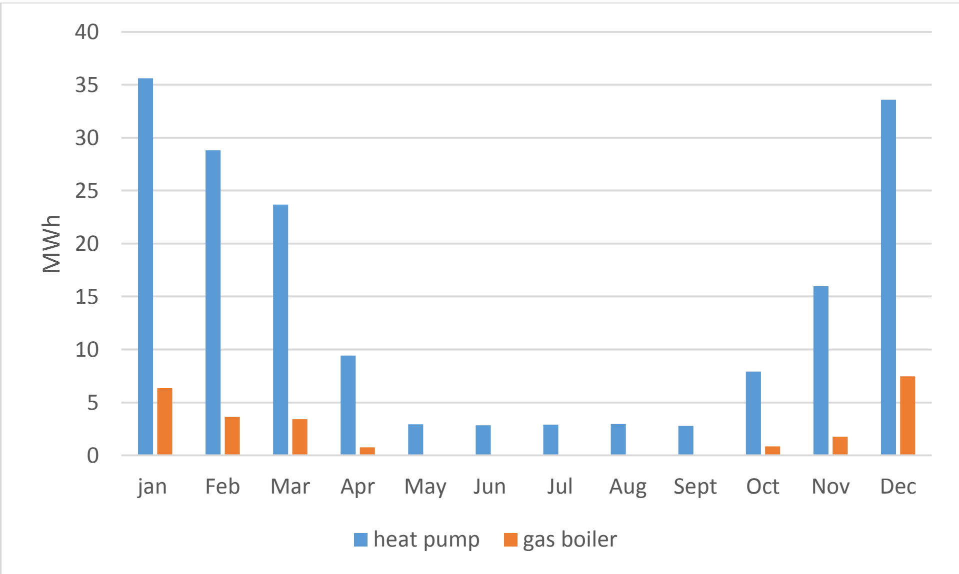
Building	19	37
Natural gas [Nmc]	24	2.323
Electricity [KWh]	20.900	49.940

In the graphic are reported the reparation of consumption for the two solution.

Graphic 10: Distribution of consumption for building 19



Graphic 11: Distribution of consumption for building 38



The values of COP are calculated knowing the electric consumption and the production of heat for every month and finally for the entire year.

Table 40: Actual COP for every month

COP	year	J	F	M	A	M	J	J	A	S	O	N	D
building 19	3,50	3,25	3,45	3,60	4,13	3,71	3,84	3,96	3,89	3,75	4,37	4,04	3,22
building 37	3,39	3,20	3,39	3,54	3,86	3,13	3,23	3,30	3,25	3,16	4,02	3,90	3,17

6.2 Solar collectors system

In this second solution, solar collector are adopted to produce DHW with a capacity able to cover almost the entire consumption in summer. The remaining part of heat for DHW is produce with a condensation boiler in a centralise plant.

For these solutions are adopt solar flat plate collectors. First is evaluate the position and orientation of the roof and measure the available area.

Table 41: Installed conditions for solar collectors

Building	19	37
Azimuth [°]	40	-70
Tilt	20	25
Available area [m^2]	60	25

6.2.1 Surface of solar collectors

Principal problem for solar system is the great difference of performance during the year. For this purpose is decided to produce only DHW with solar and avoid an excessive oversizing in the summer time. Moreover this problem is not eliminate consider only the DHW production. Oversizing problem create problem of stagnation. In these circumstances the vessel connect with solar connector can't accumulate energy and the pump that move primary fluid remain stopped when temperature exceed 90°C. Temperature in solar collector increase quickly and reach the value of evaporation, pressure increase due to the vapour. Temperature and pressure continue to increase in the solar collector until when is establish an equilibrium between collector and air temperature. Radiation reheat the collector but the collector dissipate heat due to the difference of temperate from the environment. This process need some precaution in the design of system but also decrease the overall efficient of solar collectors because part of radiation is not transform in heat. Stagnation can be reduced increasing the vessel dimension but comport more initial cost and get worse the performance in winter time when bigger vessel comport lower water temperature. In stagnation, solar collector efficient is equal to zero because all radiation is dissipate and system don't produce hot water. The efficient of solar collectors indicates the percent of radiation which is converted in useful thermal energy and it is due to many factors. A part of radiation that reaches the collector is lost because is reflected from the glass and absorber. The relations between irradiation that reach the glass and the part that is converted in useful thermal is define the efficient η_0, which is called optical efficiency. As said, when is presents difference of temperature between external air and water, part of the energy is released for radiation and convention and the real efficient is lower than the optical value. These losses are define between two coefficient: K_1 and K_2 and the difference of temperature ΔT between absorber and external air. Efficient is express like:

$$\eta = \eta_0 - \frac{K_1 * \Delta T}{E_g} - \frac{K_2 * \Delta T^2}{E_g}$$

η: Collector efficient

η_0: Optical efficient

K_1: Heat losses coefficient [$W/m^2 * K$]

K_2: Heat losses coefficient [$W/m^2 * K^2$]

ΔT: Difference of temperature

E_g: Radiation [W/m^2]

Standard value of η_0 is between 0,7-0,8 and represent the maximal value of efficient. For these reasons is important to consider many factor in the dimension and decide which value of radiation is better to adopt to kept high the value of yearly efficient. For example in a perfect day and in optimal condition radiation can arrive to 8 KWh/m^2 but only a part of this is converted in useful energy, not more than 60-65% and the maximal energy for meter square is about 4,8 KWh. Radiation decreases for another 10% considers the non-optimal orientation an inclination of the roofs in this situation. A first dimension of solar collector is made with this value and after with EnergyPro is verified the correct dimension and if the configuration permit to cover the entire demand in summer period and avoid frequently situation of stagnation. Final dimensions are decided considers the area of commercial panel. The chosen is the model Vitosol 100-F produced by Viesmann with an absorption area of 2, 32m^2.

Table 42: Solar collectors surface

Building	**19**	**38**
Panel number	3	10
Area [m^2]	6,96	23,2

6.2.2 Gas Boiler

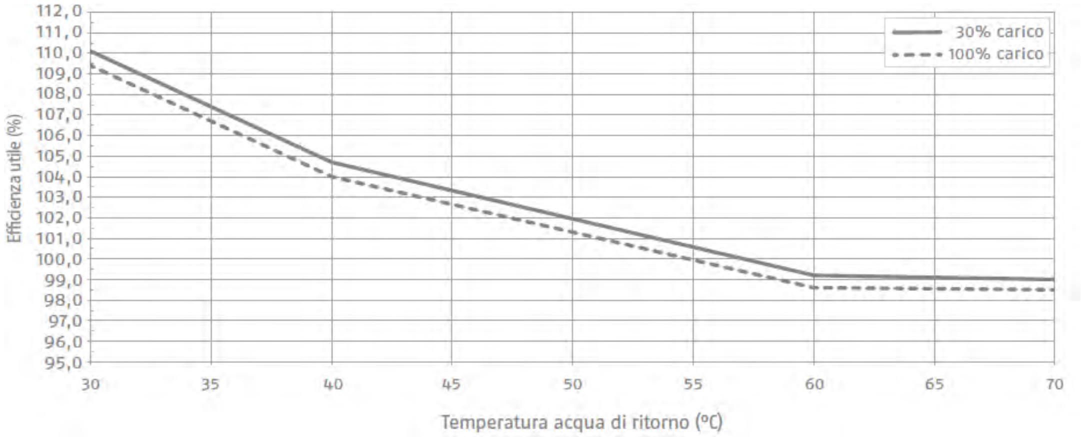
Gas boiler have to supply heat for heating and for DHW. In wintertime the contribute of solar collectors is negletable in cold and cloudy days and then the dimension of boiler is completely independent to them presence. For these installations are available wall-mounted boilers with condensation. These boilers present high efficiencies that usually increase at partial load and when return water temperature is lower then 55- 60°C. Model are chosen with a higher security coefficient respect-heating peak including DHW production.

Table 43: Performance of condensation boiler

Building	**19**	**38**
Model	CONDEXA PRO 50M	CONDEXA PRO3 115
Max burn power	45	115
Min burn power	15	23
Nominal power 80-60	44,2	113,4
Nominal power 50-30°C	48,5	124,9

Like in heat pump system, climatic regulation controls the flow temperature because in this way is possible to increase the condensation process and the efficient. An example of efficiency trend is showed for model CONDEXA PRO3 115.

Figure 14: Example of efficiently trend for condensation boiler



Return temperature is between 35 to 50°C when external temperature change from 15 to -5 °C. Efficiently is express in function to the external temperature approximating the trend under temperature of 40°C that present a different tilt. Correlation between efficiently and return temperature result:

- CONDEXA PRO 50M $\eta = (288 - T) * 0{,}33 + 102 \;\; with - 5 < T < 15$
- CONDEXA PRO3 115 $\eta = (288 - T) * 0{,}33 + 101 \;\; with - 5 < T < 15$

6.2.3 Storage tank

The solution for the two buildings is to use two different storage tanks with exchanger coil, one connect with the solar collectors and another with the gas boiler. Two tank are connecting in serial but in summer time, water from solar tank can be used directly. In winter time solar is use only to preheating water and the second tank permits to produce hot water guaranteed to the boiler the correct buffer to produce water in indirectly way. Solar collector can discharge heat working with a tank a low temperate independent to the presence of boiler. Water that exit from the first tank is controlled with a three way valve, if its temperature is enough for DHW it is send in the system, in other case water is send in the tank connect with boiler that receive water with a temperature higher than the aqueduct temperature. In the second tank water have a project temperature that is fix in 80°C for DHW product with boiler. Second tank is dimensioned considering the UNI 9182 and the heating power available between the difference from installed power and maximum peak of heating present for heating. Max temperature is fix in 80°C and duration of pick and consumption are the same calculated for heat pump. For the first tank, connect with solar collectors is evaluated the minimum volumes which can storage all the energy produce in a summer day consider an initial temperature of 15°C and a final of 90°C and a radiation of 4,3KW/m^2 day. The reason of this limit is that in normally conditions, peaks of consumption are in the morning or evening. Result necessary to storage all the energy produced during the day. It is also improbably that during the day the consumption is completely zero and storage is completely empty with a temperature of 15°C.

Table 44: Storage tank dimensions

Building	**19**	**38**
Solar collector tank [l]	200	1000
Gas boiler tank [l]	200	500

6.2.4 System simulation

Model has been divided in two part one for DHW and another for heating. This is possible because there is only one gas boiler that have to satisfy both consumption when solar collector are not enough for DHW. Consumption of gas boiler can be summed linearly after the two simulations. Two simulations are preferable because in this way is possible to model two differents efficient for gas boiler. When it works for heating efficient, depend to the return temperature while when it works for DHW a return temperature of 55°C is taken. Solar collector can be implemented easily in the model with the possibility to insert the adsorption area, angle of tilt and azimuth. The presence of external shading is neglected because buildings are high respectively 10 and 24 m. Energy Pro ask the temperature at which the circulation pump is activated to provide primary fluid to the storage tank. After some attempts a good profile result

- 25°C form 1 January to 28 February
- 35°C from 1 march to 30 April
- 45 from 1 may to 31 August
- 35 form 1 September to 31 October
- 25° form 1 November to 31 December

In the model are inserted the parameter η_0, $K_1$and K_2 for the solar collector Vitosol 100-F.

Table 45: Solar collectors efficient

	Value
$\boldsymbol{\eta_0}$	76
$\boldsymbol{K_1\ [W/m^2 * K\ ]}$	4,14
$\boldsymbol{K_2\ [W/m^2 * K^2\ ]}$	0,0108

Storage tank is considered the only one directly connect with solar collector with a maximal admissible temperature of 90°C.

In the other simulations, made for heat pump and straw boiler external condition was used only to define the load distribution in the year or for example with heat pump to calculate the instant COP but the energy demand was a prefixed value. In this simulation radiation influence directly the yearly thermal production and using the data referee to one year is possible to commit some error. For this reason, simulation is made in three different years with the radiation and temperature data referee to 2008, 2009, 2010. Quantity of thermal energy produced with solar collector will be calculated like the average between these three years. Gas boiler efficient for DHW production is 100% considers a return temperature from exchange coil of about 55°C. For heating in wintertime efficient is correlated with the external temperature and depends to the flow temperature control by climatic regulation. For heating are valid the same consideration used for heat pump system. The only differences are due to the temperature use for climatic regulation that used higher temperature and a different trend respect heat pump.

6.2.5 Result

Graphic 12: Solar DHW production in 2008, 2009, and 2010 for building 19

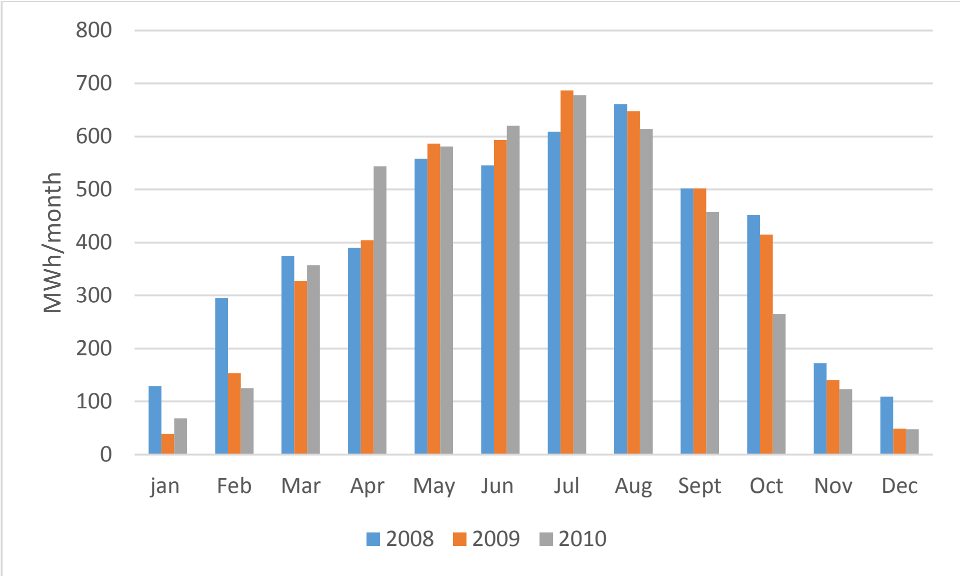
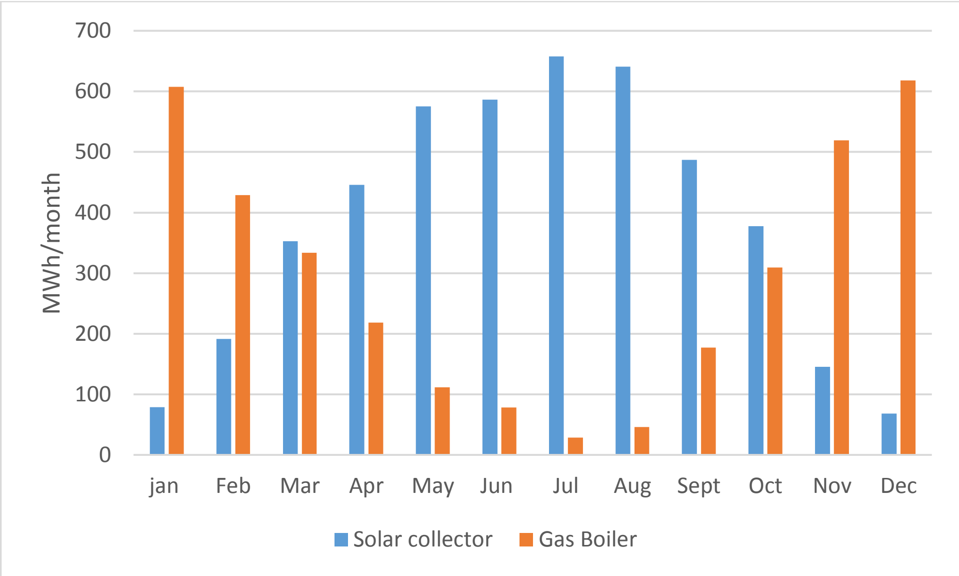


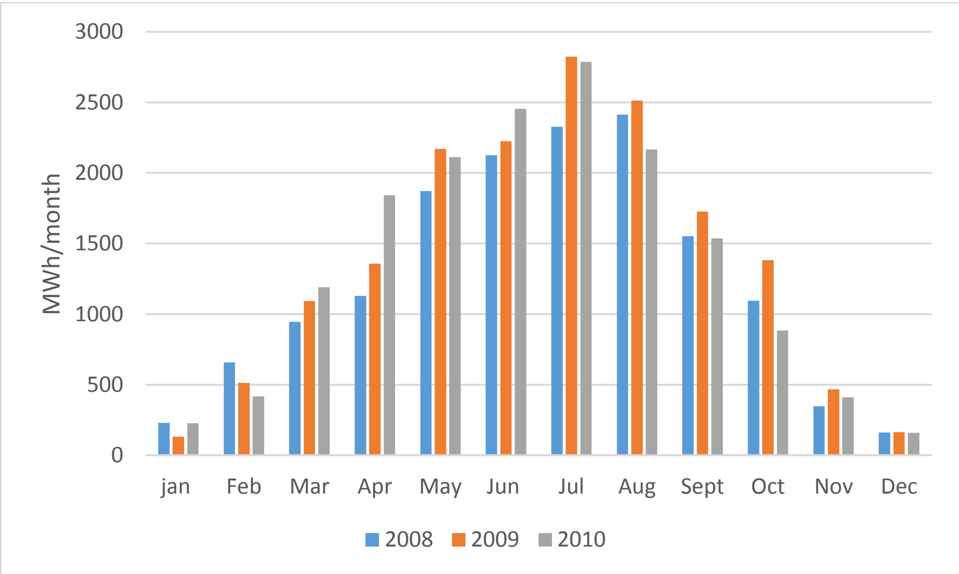
Table 46: Monthly consumption for the system in building 19

	year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
supply energy [KWh]	73185	15602	12370	10375	4000	687	665	687	687	665	4073	7922	15454
DHW energy [KWh]	8085	687	620	687	665	687	665	687	687	665	687	665	687
solar energy [KWh]	4608	79	191	353	446	575	586	658	641	487	378	145	69
DHW from solar energy [%]	57	11	31	51	67	84	88	96	93	73	55	22	10
gas boiler heat production [KWh]	68577	15523	12179	10022	3554	111	78	29	46	177	3695	7777	15386
gas boiler fuel consumption [KWh]	65747	14790	11654	9631	3450	111	78	29	46	177	3603	7530	14647
gas boiler fuel consumption [Nmc]	6848,7	1540,6	1214,0	1003,2	359,4	11,6	8,2	3,0	4,8	18,5	375,3	784,4	1525,7
Gas boiler efficient	1,04	1,05	1,05	1,04	1,03	1,00	1,00	1,00	1,00	1,00	1,03	1,03	1,05

Graphic 13: Repartition of DHW production between gas boiler and solar collector in building 19



Graphic 14: Solar DHW production in 2008, 2009, and 2010 for building 38

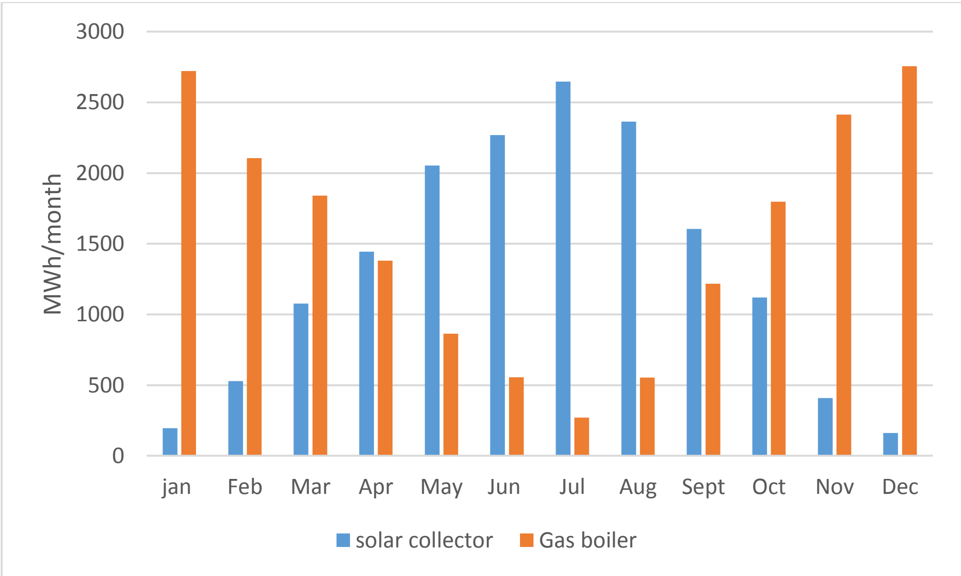


Graphic 15: Monthly consumption for the system in the building 19

	year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
supply energy [KWh]	202145	41363	32921	27888	11420	2917	2823	2917	2917	2823	11646	21530	40981
DHW energy [KWh]	34345	2917	2635	2917	2823	2917	2823	2917	2917	2823	2917	2823	2917
solar energy [KWh]	15871	196	529	1076	1443	2052	2268	2647	2364	1605	1121	409	162

DHW from solar energy [%]	46	7	20	37	51	70	80	91	81	57	38	14	6
gas boiler heat production [KWh]	186274	41167	32392	26813	9977	865	555	270	553	1218	10525	21121	40820
gas boiler fuel consumption [KWh]	179056	39295	31053	25816	9714	865	555	270	553	1218	10290	20494	38933
gas boiler fuel consumption [Nmc]	18652	4093	3235	2689	1012	90	58	28	58	127	1072	2135	4055
Gas boiler efficient	1,04	1,05	1,04	1,04	1,03	1,00	1,00	1,00	1,00	1,00	1,02	1,03	1,05

Graphic 16: Repartition of DHW production between gas boiler and solar collector in building 38



7. Economic evaluations

In this chapter are evaluated the cost for the realisation of DH system and the alternative solutions. For all systems is considered the presence of government incentives and at the end are compared the initial costs, the cost of heat and the convenience is evaluated.

7.1 Cost for the realisation of district heating

7.1.1 Grid cost

Cost are calculated using precalculated value. These costs are referee for every meter of excavation and include both tubes, flow and return. Price are calculated for standard buried condition and included all works necessary to realise trench, laying of pipelines and resetting the previous conditions. They include also problem due to the interference with other subservice present in the ground. Total lengths are calculated for every DN and after multiply for the civil and tubes cost. Overall grid cost result 451.139 €.

Table 47: Cost for meter of tubes (flow and return)

DN	Length [m]	Civil work	tubes and connection	total cost [€]
25	32	150	65	6.871
32	89	150	65	19.240
40	70	150	65	15.029
50	415	150	75	93.330
65	399	155	90	97.811
80	237	165	110	65.300
100	264	170	120	76.474
125	109	195	150	37.583
150	100	215	180	39.500
Total cost				45.1139

7.1.2 Connections with buildings

Cost of connection with every flat includes a lot of variable, for example the possibility to install a centralise units for every building or for every single flat. In this situation is considered the possibility to install exchange units in every flat with instantaneous production of DHW and then is not consider the presence of system already install in the flat like storage tank with coil. Cost for a basic units is 1800€ including system for produce DHW, and measure system (model satk30105 produce by Caleffi). Additional cost of 500€ is considered for internal connection that include cost of tubes and labour. Every building needs tubes for the connection with the grid. In large buildings, internal distribution system is realised with more columns and best position to enter inside usually is not the nearest point of secondary line. For this reason, tubes with a length like the semi-perimeter of building are consider for this step. Price of 65 €/m is considered for these tubes, same price used for the grid, while civil cost are decreased to consider that these tubes cross private zone, usually with garden and required lower depth of buried. Price of civil work is half-then in public area and equal to 75€/m for all diameters.

The overall cost for the connection between grid and buildings is estimate in 249.000 € while the cost for flat units and their connection is 1’370’000 €.

Table 48: Cost for the connection of every building

Building number	Number of flat	connection cost [€]	unit cost [€]
1	55	40.600	126.500
2	8	4.340	18.400
3	4	3.780	9.200
4	13	6.510	29.900
5	1	3.360	2.300
6	2	3.360	4.600
7	10	7.700	23.000
8	17	9.870	39.100
9	1	3.150	2.300
10	2	3.010	4.600
11	9	4.620	20.700
12	9	4.830	20.700
13	2	3.080	4.600
14	7	4.620	16.100
15	8	4.550	18.400
16	1	3.150	2.300
17	7	4.270	16.100
18	6	4.410	13.800
19	6	4.410	13.800
20	9	3.220	20.700

21	8	4.270	18.400
22	5	4.970	11.500
23	1	2.590	2.300
24	2	4.620	4.600
25	9	4.550	20.700
26	24	9.240	55.200
27	19	9.240	43.700
28	22	4.900	50.600
29	22	4.760	50.600
30	13	5.110	29.900
31	35	8.470	80.500
32	13	4.410	29.900
33	17	4.550	39.100
34	27	8.400	62.100
35	16	4.200	36.800
36	17	5.180	39.100
37	17	4.690	39.100
38	31	5.670	71.300
39	31	5.670	71.300
40	31	5.670	71.300
41	31	5.670	71.300
42	31	5.670	71.300
Total		249.340	1.377.700

7.1.3 Cost for boiler house

Cost for boiler is divided in two components, one for civil structure and another for boilers and all service systems like storage, feeding system, electrical plant, and fuels storage. The building that contain boiler house have an overall dimension of 28,60 meter X 16,60 meter and cover an area of 470m^2. The area necessary to build boiler house need major dimension and is consider a distance of 3 meter between the side of the building and 10 in the front side to create a parking for trucks or other uses. Area of 950 m^2 is necessary to realise boiler house. Price of area is 100€/m^2 and cost of building is estimate in 400€/m^2 considered a concrete structure in this range of dimensions. An extra cost of 20% is usually need for the realisation of fire protection industrial plant. Cost of area and building can calculated respectively in 100.000€ and 240.000 €.

Price of component is calculated through hydraulic price list and estimates provide from manufactories. Price for the main component in boiler house are reported.

Table 49: Cost for the realisation of boiler house

Component	*Cost*
Gas boiler	161’000 €
Straw boiler	150’000 €
Straw cutter line	90’000 €
Storage tank	25’000 €
Steel chimney	23’000 €
Electric plant	30’000 €
Pump station	8’000 €
Bridge crane	40’000 €
Other cost	30’000 €
Total	557’000 €

Boiler house comport globally civil and mechanical cost for 897.000€.

7.2 Operating cost for district heating

The goal in this section is to estimate the operating costs derive from ordinary management cost. They include fuel, pumping cost, boilers maintenance and other extra cost.

7.2.1 Energy costs

In chapter number three has been evaluated the average price of straw. Average price resulted 56,1 €/ton but including transport, in according with the commodity exchange the price arrives to 100€/ton. Cost of natural gas benefits of taxation advantage for DH and price can fix in 0,45 Sm^3. Pumping cost consider a price of 0,20 €/KWhe. Energetic costs are quantifiable in 170’074 €/year equal to 33,5 €/MWh of net energy.

Table 50: Price for fuels

Fuel	Consumption	Price	Price [€/KWh]	Yearly cost [€]
Straw	1338 tons	100 €/ton		133.800
Natural Gas	69139 Sm^3	0, 45 Sm^3		31.108
Electricity	29080 KWh	0,20 €/KWh	0,20	5.816
Total cost				170.724

7.2.2 Other costs

Other cost are due to the ordinary maintenance are 25 € MWh. Moreover is consider the presence of two technical with the rule to manage and setting the boiler system, provide the unload and load of straw from truck and refuel the straw line cutter. Cost is fixed in 60.000 €/ year.

7.4 Economic balance

The price of energy provide is an equilibrium between the remuneration of the investment for the company that realised DH and the saving that the customers can have replacing old plant. The determination of minimal cost have to guarantee a minimal profitability of the investment. Price of heat is determinate with an investment plan. In this way is possible to determinate the remunerability. Investment plan considers a coverage of 90% respect the maximal energy calculate for the area. Energy is not supply in the first year for all user but the value of 90% is reached in 5 years consider the follow trend.

Table 51: Trend of new user

year	Percent of coverage
1	40%
2	55%
3	70%
4	80%
5	90%

The contribute of new white certificates is increased for the quota that compete with the new power connect in every year and them value is calculated follow the method report in Appendix A1.

Using the data of consumption obtained with the simulation and replaced systems feed by natural gas the plant saves 546 TEP. Considering a duration factor, the total amount useful for incentives is equal to 1835 TEE year. Price of certificate about 90€/TEE and the overall theoretical incentive are equal to 165.150€/year for 5 years. Initial cost for the project include all cost for DH grid and boiler house increase with IVA amount of 22%. Interest, on the money needs to pay the initial cost are calculated with 3% rate years while all cost, included fuel, increase of 1,5%. Three different situations are analyzed: the first two, aim to consider the lowest price as possible for heat while the third exploit a higher price of heat but guarantee a considerable cover of initial cost of connection form the company. Price of heat is determinate checking that the value of internal rate of return will be at least 10%. Economic plan is calculated for a period of 20 years because is a reasonable time for the duration of the main components present in the boiler house without extraordinary work of maintenance. NVP calculates a discount rate of 2% and not consider the cost of the area because is not a depreciable asset. Cost of grid and building are consider only for 2/3 of their initial cost because duration of these infrastructures is almost 30 years.

The presence of tax rebate in the chapter three make the economic analysis more compels but now some simplifications will be adopted. Tax rebates have the purpose to give an incentive only for the final customers and the provider represent only the organ that permit this. Tax rebate for the installation of exchange unit are 20,66 €/KW. This amount is completely ignored in this part. The provider realize the connection and after make a discount, which considers the future rebate, the customer will pay the remaining part of the cost and then the cost of connection don't represent a real cost for the company. Tax rebate over heat permit to define two different price, one that the customer have to pay and another that the provider receives. The price for customer is calculated starting from a price for KWh increases of 10% of Iva and decreases for the presence of tax rebate that are immediately subtracting in the bill. Price for customers is then correctly calculated. For the company is different, infect it receives the payment relatively to the final price for KWh and after can received the rebate from the government and obtain the entire price of heat. In this analysis is consider that the company received immediately the correct price that it wants to obtain from the heat. In the reality, the situation is more complex and the company can have back the money that it has not obtain from the customer with a compensation or repayment. Generally, the first solution is not preferable because especially in the first years the cost are high, the profits are low and the tax to pay are limited. The only compensation can make the rebate impossible. The value of tax rebate consider also the percent of heat produce with natural gas that represent the 11% and comport a reduction of tax rebate for KWh reducing the value of 21,93 €/MWh to 19,50 €/MWh.

Table 52: Sell price for the customer

Solution	1	2	3
Nominal value [€/MWh]	80	90	105
Sale value with Iva [€/MWh]	88	99	115,5
Tax rebate [€/MWh]	19,49	19,49	19,49
Final price for the customer [€/MWh]	68,50	79,50	96,00

In the first and second solution, cost of heat is 80 and 90 €/MWh and increases with the fixed value of inflation equal to 1,5%. In third solution an incentive of 1500€ to cover part of the initial cost is given to the customer. This amount permit, adding the government incentives give as tax rebate to cover the major part of the connection cost that change in relation to the typology of building. Price of energy is obviously higher and fixed in 105€/MWh for the first year.

Table 53: Economic plan, 1° solution

year	cash flow [€]	fuel cost [€]	extra cost	financing cost [€]	heat sales	TEE [€]	final balance [€]	actualized flux [€]
1	-1.645.780	68.290	65.980	41.145	159.200	64.460	48.246	49.542
2	-1.597.534	95.307	66.970	39.938	222.184	88.633	108.601	106.472
3	-1.488.933	123.119	67.974	37.223	287.021	112.805	171.509	164.849
4	-1.317.424	142.818	68.994	32.936	332.944	128.920	217.117	204.594
5	-1.100.307	163.080	70.029	27.508	380.180	145.035	264.599	244.448
6	-835.708	165.526	71.079	20.893	385.883	80.575	208.960	189.261

7	-626.748	168.009	72.145	15.669	391.671	56.403	192.250	170.713
8	-434.498	170.529	73.228	10.862	397.546	32.230	175.157	152.485
9	-259.341	173.087	74.326	6.484	403.510	16.115	165.728	141.447
10	-93.613	175.684	75.441	2.340	409.562	0	156.097	130.615
11	62.484	178.319	76.572	0	415.706	0	160.814	131.924
12	223.299	180.994	77.721	0	421.941	0	163.226	131.277
13	386.525	183.709	78.887	0	428.270	0	165.675	130.634
14	552.200	186.464	80.070	0	434.694	0	168.160	129.993
15	720.360	189.261	81.271	0	441.215	0	170.682	129.356
16	891.042	192.100	82.490	0	447.833	0	173.243	128.722
17	1.064.285	194.982	83.728	0	454.551	0	175.841	128.091
18	1.240.126	197.906	84.984	0	461.369	0	178.479	127.463
19	1.418.605	200.875	86.258	0	468.289	0	181.156	126.838
20	1.599.761	203.888	87.552	0	475.314	0	183.873	126.216

Table 54: Economic plan, 2° solution

year	**cash flow [€]**	**fuel cost [€]**	**extra cost**	**financing cost [€]**	**heat sales**	**TEE [€]**	**final balance [€]**	**actualized flux [€]**
1	-1.645.780	68.290	65.980	41.145	179.100	64.460	68.146	49.542
2	-1.577.634	95.307	66.970	39.441	249.956	88.633	136.872	134.188
3	-1.440.762	123.119	67.974	36.019	322.898	112.805	208.591	200.491
4	-1.232.171	142.818	68.994	30.804	374.562	128.920	260.866	245.820
5	-971.305	163.080	70.029	24.283	427.703	145.035	315.346	291.331
6	-655.959	165.526	71.079	16.399	434.119	80.575	261.689	237.020
7	-394.270	168.009	72.145	9.857	440.630	56.403	247.021	219.348
8	-147.249	170.529	73.228	3.681	447.240	32.230	232.032	201.997
9	84.783	173.087	74.326	-2.120	453.948	16.115	224.770	191.839
10	309.552	175.684	75.441	0	460.758	0	209.633	175.412
11	519.185	178.319	76.572	0	467.669	0	212.778	174.552
12	731.963	180.994	77.721	0	474.684	0	215.969	173.696
13	947.932	183.709	78.887	0	481.804	0	219.209	172.845
14	1.167.141	186.464	80.070	0	489.031	0	222.497	171.997
15	1.389.638	189.261	81.271	0	496.367	0	225.834	171.154
16	1.615.472	192.100	82.490	0	503.812	0	229.222	170.315
17	1.844.694	194.982	83.728	0	511.369	0	232.660	169.480
18	2.077.354	197.906	84.984	0	519.040	0	236.150	168.650
19	2.313.504	200.875	86.258	0	526.826	0	239.692	167.823
20	2.553.196	203.888	87.552	0	534.728	0	243.288	167.000

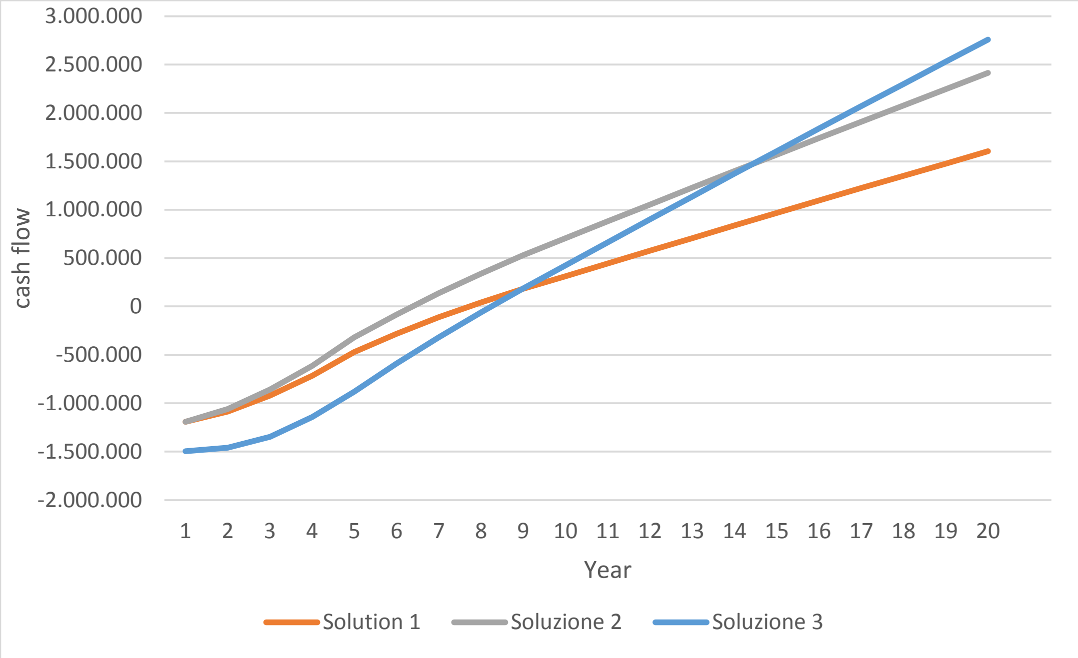
Figure 15: Economic plan, 3° solution

year	cash flow [€]	fuel cost [€]	extra cost	financing cost [€]	Incentive [€]	heat sales	TEE [€]	final balance [€]	actualized flux [€]
1	-1.645.780	68.290	65.980	41.145	360.000	208.950	64.460	-262.004	-253.289
2	-1.907.784	95.307	66.970	47.695	135.000	291.616	88.633	35.277	34.586
3	-1.872.507	123.119	67.974	46.813	135.000	376.715	112.805	116.614	112.086
4	-1.755.893	142.818	68.994	43.897	90.000	436.989	128.920	220.200	207.499
5	-1.535.693	163.080	70.029	38.392	90.000	498.987	145.035	282.521	261.005
6	-1.253.172	165.526	71.079	31.329	0	506.472	80.575	319.112	289.029
7	-934.061	168.009	72.145	23.352	0	514.069	56.403	306.965	272.576
8	-627.096	170.529	73.228	15.677	0	521.780	32.230	294.575	256.446
9	-332.521	173.087	74.326	8.313	0	529.606	16.115	289.995	247.508
10	-42.526	175.684	75.441	1.063	0	537.551	0	285.363	238.779
11	242.837	178.319	76.572	0	0	545.614	0	290.722	238.494
12	533.560	180.994	77.721	0	0	553.798	0	295.083	237.324
13	828.643	183.709	78.887	0	0	562.105	0	299.509	236.161
14	1.128.152	186.464	80.070	0	0	570.537	0	304.002	235.003
15	1.432.154	189.261	81.271	0	0	579.095	0	308.562	233.851
16	1.740.716	192.100	82.490	0	0	587.781	0	313.191	232.705
17	2.053.907	194.982	83.728	0	0	596.598	0	317.888	231.564
18	2.371.795	197.906	84.984	0	0	605.547	0	322.657	230.429
19	2.694.452	200.875	86.258	0	0	614.630	0	327.497	229.300
20	3.021.948	203.888	87.552	0	0	623.849	0	332.409	228.176

Table 55: Economical indices for the three solutions

Solution	1	2	3
VAN [€]	1.602.980	2.410.729	2.757.273
IRR [€]	13,73%	18,11%	14,43%
payback period [years]	9.5	7.2	9.6

Figure 16: Trend of VNP for the three solutions



7.5 Existing system

For the buildings looked as reference is hypnotizes that old systems are a private gas boilers without condensation. Yearly efficient, for a wall mounted boiler, with high capacity of partialisation is about 90% with instant preparation of DHW. Life cycle is 15 years after that is necessary to replace the boiler. Cost of boiler with installation is consider 1200€ and a yearly cost of 100 € including for ordinary and extraordinary cost including taxation. Cost of natural gas is 0,85€/mc for domestic bill including all tax. Repartition of boiler cost is made dividing the price for 15 years. Overall costs consider that in every flat of the buildings 19 and 38 there are boilers with the explained cost. Fuel consumption and cost are considered for the entire building and after all cost are divided for the yearly provide energy.

Table 56: Cost for KWh provide from the existent system

	building 19	*building 38*
Maintenance	600€	3100€
Natural gas	6857€	18947 €
Heat price	0,106 €/KWh	0,114 €/KWh

7.6 Heat pump system

7.6.1 Realisation costs

Thermal power station is composed of heat pump, reserve gas boiler, storage vessel for DHW and another one with a small demission to increase the inertia of hydronic circuit. Reduced dimension of all these components involve in the possibility to not consider extraordinary masonry cost. Hot water is delivered with two different circuits one for heating and another for DHW. Cost of two system is the same because is considered a recirculation system. Repartition of consumption is made in two different way. For heating, there is a system with units composed by circulation pump and energy meter. DHW is produce with a fixed temperature and then a flow meter is enough to evaluate the consumption.

Table 57: Cost for the heat pump system

	building 19	*building 38*
Gas boiler	5900€	11200€
Heat pump	21300€	31200€
DHW system	3600€	4300€
Flat unit	2100€	10850€
Energy and flow mater	1800€	9300€
Flat connection	4500€	23250€
Total	39200€	90100€
IVA	3920€	9010€
incentives	4116€	6085€
Initial investment	39004€	93025€

7.6.2 Cost of heat

Cost of heat includes fuel and maintenance. Yearly consumption of fuel has been calculated with Energy Pro considering the losses of the production system. After the addition of maintenance costs is calculated the final price of every KWht supply to the system. Cost of fuels is 0,85€/Smc for natural gas and 0,25 €/KWh for electricity.

Table 58: Final cost for KWh for the energy

	building 19	*building 38*
Maintenance	300 €	500 €
Electricity	5225 €	12485 €
Natural gas	20 €	1974 €
Heat price	0,079561 €/KWh	0,077672 €/KWh

7.7 Solar collectors system

7.7.1 Realisation costs

Thermal plant is composed of solar collectors install on the roof and relatively tank. Condensation boiler and another tank for DHW production. Distribution system is the same use for heat pump, with separate circuit for heating and DHW that is always produce in a centralising way and same system of meter.

Table 59: Cost for the solar collectors system

	building 19	*building 38*
Gas boiler	6500 €	11000 €
Solar collector	3400 €	11500 €
Solar tank	2000 €	4000 €
Boiler tank	2000 €	3000 €
Flat unit	2100 €	10850 €
Energy and flow mater	1800 €	9300 €
Flat connection	4500 €	23250 €
Total	22300 €	72900 €
IVA	2230 €	7290 €
Incentive	2366 €	7888 €
Initial investment	22164 €	72302 €

7.7.2 Cost of heat

Cost of heat is calculated with the same method and energy tariff adopted for heat pump.

Table 60: Final cost for KWh for the provide energy

	building 19	*building 38*
Maintenance	300 €	500 €
Natural gas	5821 €	15854 €
Heat price	0,0878 €/KWh	0,0849 €/KWh

7.8 Economic comparison

The economic comparison between the three alternatives is made taking a reference the existing situation. From initial investments is subtracted the cost of gas boiler and the same is made for the price for KWht. For every situations is calculated the difference of price between KWh for the existing situation and new plant. Economic advantages are calculated considered these differential values. A system result convenient if is able to cover in a useful number of years the initial difference of cost. Overall costs are subdivided for the number of flats present in the building, in this way the economic advantages are refereed to an average family who lives there. The price of all fuel are calculated with an 1,5% growth rate. Value of NPV is calculated with a discount rate of 2%. In all case, the cost for DH connection is net from the incentives give to the final customer in form of tax rebate.

7.8.1 Building 19

Table 61: Initial cost and energy price for the building 19

	Initial investment [€]	**Major investment [€]**	**Energy price [€/KWh]**	**Difference of price [€/KWh]**
Gas boiler	7.200	0	0,108	0
Heat pump	39.004	31.804	0,080	0,028
Solar collector	22.164	14.964	0,088	0,020
DH solution 1	18.828	11.628	0,0685	0,039
DH solution 2	18.828	11.628	0,0795	0,028
DH solution 3	9.828	2.628	0,096	0,012

Graphic 17: NPV for the different solutions in building 19

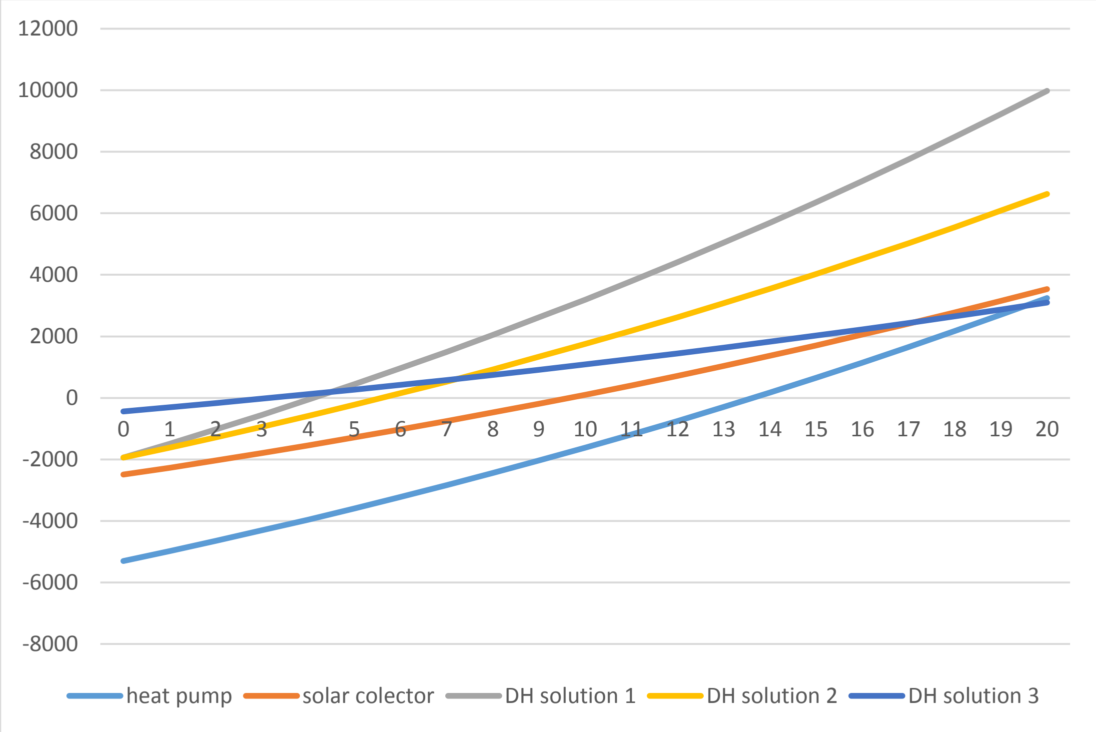


Table 62: Initial investment and benefit for a single costumer in the building 19

	Initial differential cost [€]	Payback period [years]	Yearly saving [€]	Percent saving
Heat pump	5.301	15	317	26,1
Solar collector	2.494	9,9	224	24,9
DH solution 1	1.938	4,1	443	44,5
DH solution 2	1.938	5,6	318	41,0
DH solution 3	438	3,2	131	14,6

7.8.2 Building 38

Table 63: initial cost and energy price for the building 38

	Initial investment [€]	Major investment [€]	Energy price [€/KWh]	Difference of price [€/KWh]
Gas boiler	37.200	0	0,1144	0
Heat pump	93.025	55.825	0,077672	0,037
Solar collector	73.302	36.102	0,084913	0,029

DH solution 1	76.740	39.540	0,0685	0,046
DH solution 2	76.740	39.540	0,0795	0,035
DH solution 3	30.240	-6.960	0,096	0,018

Table 64: NPV for the different solutions in building 38

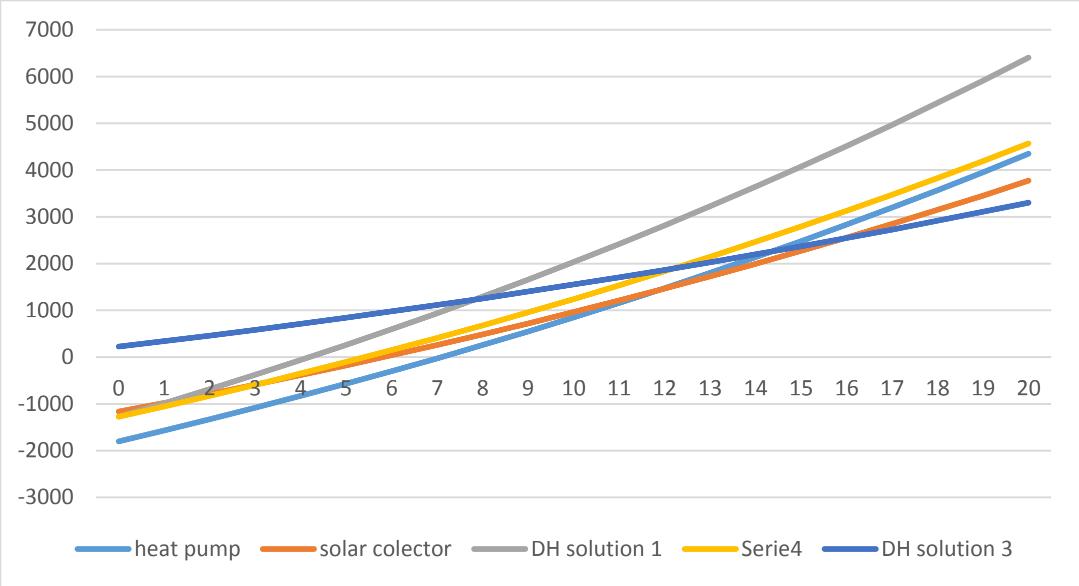


Table 65: Initial differential cost and benefit for a single costumer in the building 38

	Initial differential cost [€]	Payback period [years]	Yearly saving [€]	Percent saving
Heat pump	1.801	8,2	228	32,1
solar collector	1.165	7	183	25,8
DH solution 1	1.275	4,2	285	40,1
DH solution 2	1.275	5,4	217	30,5
DH solution 3	-225	0	114	16,1

7.8.3 Considerations

For both buildings every solution bring economic advantages except for the heat pump plan install in building 19 where the convenience is neglectable because the payback period is 15 years . For the building 38 the convenience to use centralise system is more evident. The reason must be search in the low utilisation of private gas boiler. Energy provide from each boiler is infect very limited and the boiler have a very low rate of utilisation. Cost of maintenance and amortization of boiler influence negatively the price for KWh. The different cost between the two building with energy provide from gas boiler is 0,014 €/KWht. This difference of price make every solution more convenient for building 38 with a saving rate always more than 10%.

In building 19, however the saving in terms of absolutely money is major because the consumption for every flat is higher. Heat pump result always the system with initial high price but also with the less cost for KWht. Solar collector system result more convenient then heat pump especially in building 19.

Solution with DH have completely different behaviours and using the strategy of lowest possible price or with initial incentives. The first solution permit to the customer to have major saving that arrive to 443 euro for flat in building 19 end comport initial cost lower than the other two system. The initial incentive of 1500 € force the DH manager to increase the cost for KWh and sold the energy with a price similar to the replaced system. Initial investment results in these circumstances reduced with less saving of money. In the building 38 the initial incentive of 1500€ make the solution cheaper than replace private boiler. The solution that appear more convenient for customer is the first with a lowest price of energy but moreover present a non-treasurable initial cost while second solution however do not expose the customer to a high initial cost . Initial contribute seems more convenient for the user that have a low consumption. This permit to cover the initial cost in a briefly time.

8. Environmental benefits

8.1 Fossil fuels emissions

Carbon dioxide emission and the reduction of primary energy consumption are an important factor to evaluate although, usually, for the final customer, this aspect have a secondary importance and is pone behind the economic advantages. The authorities give a lot of incentive for renewable energy to obtain the prefixed goal for the reduction of emission as was visible in the account balance. The analysis that is now realised considers before the solution between the alternatives studied for the building 19 and 38 and after an analysis to evaluate the benefit of the entire DH plant.

First is necessary define the value of CO2 emission and the equivalence in TOE for the fossil fuels used in the systems.

Table 66: Emission and TOE for the fossil fuels

Fuel	Quantity	CO2 Emission [g]	TOE
Natural gas	1 Nmc	1937	0,82
Electricity	1 KWhe	564	0,187
Gas oil	1 l	2621	1,08

8.2 Fossil fuels in the straw chain

Biomass are normally considered a fuel with zero emission but realty the process of handling, moving and transport need and consume fossil fuels. Straw is a waste product in the cultivation of cereal and in same case it can be used for other purpose. When this does not append straw is left on the ground and buried with plowed. For these reasons, only the three-mentioned operations are considered to evaluate the consumption of gas oil. Operations connected with the grow of cereal are completely independent because they can not be eliminated or reducing without the straw handling. Moreover, the convenience to use straw is presented only after the harvesting of cereal that remain the first activity like economical return. Situation is then completely different form the cultivation of oils seed or other biomass that are expressly cultivate for energetic purpose. Although are not considered eventually other disadvantages derives for the subtracting of biomass matter to the land. Consumption of fossil fuels in the process is calculated with the follow observation:

- Handling: Considering an average dimension of round baler, which are until 5/tons hour. The tractor that move the machine needs a power 80-90 CV and consume until 15l/h of gas oil.
- Loading/ unloading: it is calculated that the straw is storage in a private barn and after that transport in the boiler house the week before the combustion. This need four operation of load/ unload but the last one is made with electric bridge crane and is not considered. Every displacement need about 5 minutes for ton with a fork machine with a consumption of 10 l/h.
- Transport: is considered the first displacement between the field and barn and after between barn and boiler house. The distance include also the return way for the empty agricultural trailer for a total distance of 80 Km. It is considered that straw arrives only from the province of Verona. In one way is possible to transport 26 bales with a weight of 250 Kg. Consumption of tractor is evaluate in 0,5 l/Km

With this condition is calculated the consumption for the supply of straw that is equal to 11,7 l/ton that comport emission for 30,6 kg of CO_2 for ton of straw or rather 0,0126 TOE.

Table 67: Fossil fuels consumption in the straw handling operations

Operation	Fuel consumption [l/ton]
Handling	3
Load/unload	2,5
Transport	6,2
total	11,7

8.3 Consumption of fossil fuel for the three solution

Consumption of fossil fuels is expressed in TOE for 1 MWht. DH system have a consumption of natural gas in the integrator boiler, electricity for the pumping system and the part relatively to biomass due to the gas oil consumption. DH consumption is the repartition of the total consumption relatively to the fraction of heat use in each building. The value of TOE/MWh and gCO2/KWh for the replaced system and DH are the same for the two building.

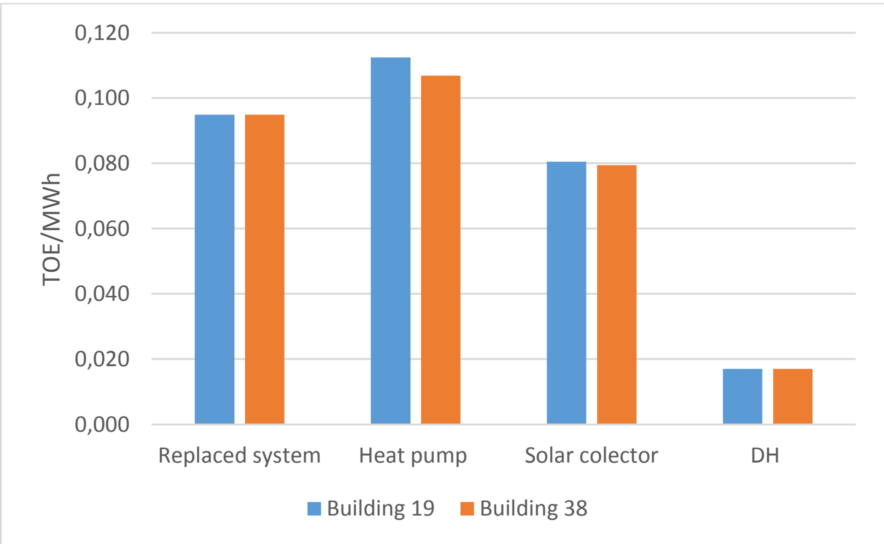
Table 68: Co2 emission and primary energy consumption for the Building 19

System	TOE	TOE/MWh	C02 [kg]	CO2 [g/KWh]
Replaced system	6,62	0,095	15.626	224
Heat pump	7,84	0,112	11.834	170
Solar collectors	5,62	0,081	13.265	190
DH	1,19	0,017	2.685	39

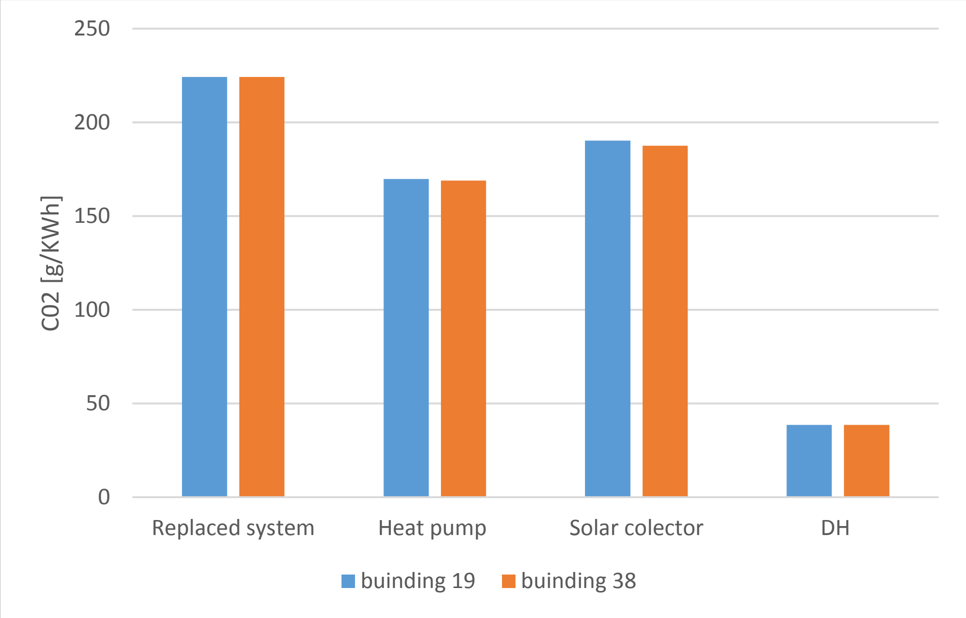
Table 69: Co2 emission and primary energy consumption for the Building 38

System	TOE	TOE/MWh	C02 [kg]	CO2 [g/KWh]
Replaced system	18,28	0,095	43.179	224
Heat pump	20,58	0,107	32.666	169
Solar collectors	15,29	0,079	36.129	188
DH	3,28	0,017	7.420	39

Graphic 18: TOE for MWh produced in different plant



Graphic 19: CO2 emission for Kwh



8.4 Benefits of district heating

The energy save in terms of TOE of fossil fuels and CO2 emission are reported for the entire plant in case that the plant will be able to provide the 90% of the district energy demand. Reduction of CO2 are more than 800 tons year with a percent reduction of 82% respect the current situation.

Table 70: Comparison between DH and replace system consumption

	Replaced system	DH
Natural gas [Smq]	518.229	62.405
Electricity [KWh]	0	26.172
Gas oil [l]	0	13.968
TOE fossil fuel	425	71
TOE reduction [%]	0	83
CO2 [ton]	1.004	172
CO2 reduction [%]	0	82

Table 71: TOE of fossil fuel for the existing system and DH

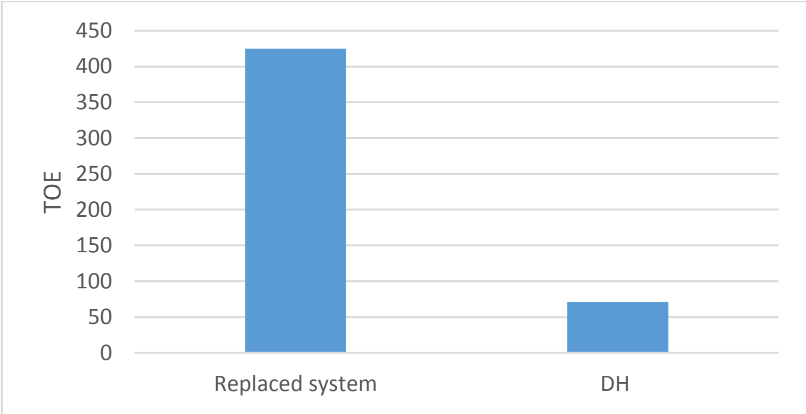
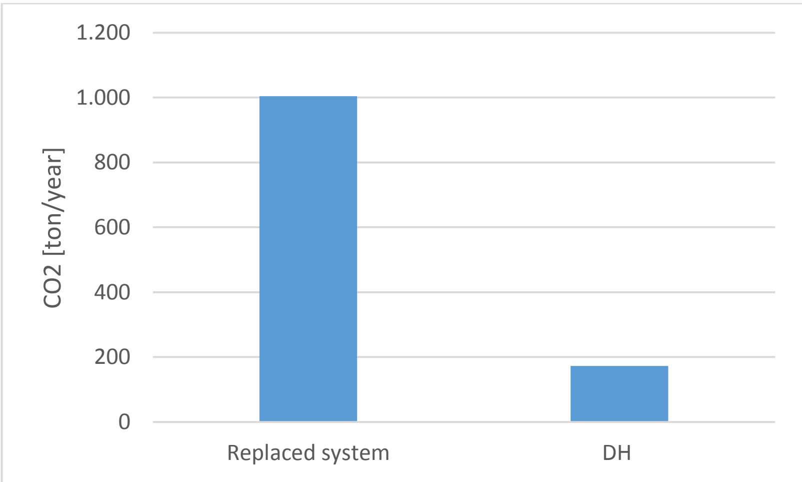


Table 72: CO2 emission in existing system and DH



Conclusions

In the study has been evaluated the possibility to realise a DH plant feed with straw and its convenience is evaluated making a comparison with the existing system and other two that exploit renewable energy. DH services from straw boiler can bring benefits in many sectors starting from the agricultural to the final customers

Benefits for the agricultural sector are implacable to the major revenues due to the sale of straw. In the project has been considered a price for the straw of 100€/ton include carry. Considering net revenue for the farmer of 50 €/ton in according to the commodity exchange. With a production of 4 ton/hectares the total revenue are increased. The sale of wheat with a production of 5,4 €/hectares with a price of 220€/ton is equal to 1188 €/ hectare is increased of 200€ or rather 17% of more revenue. This amount is even more significant considering only the earnings that are really limited while the amount of 200€ derive form the straw is net from every cost. As said, the handling of straw may impoverish the land, but this aspect has not been studied.

From the side of company the initial investment have to handle a considerable amount for the purchase of the land, construction of boiler house, installation of boilers and realisation of the grid which is calculable in 1.348.000. Moreover, all the cost for the connection with buildings and the flat units are explicable in other 1.586.000 €. Important rule is covered by the incentives give like white certificates which in five year can reach the hypothetical amount of 825.000€ if the 100% of the users will connect with DH, hypothesis that has been refused in the study. For all the solutions analysed, whit different sale price for the heat, the payback period is short then 10 years and the net present value after 20 years is always more than the initial investment.

The final price for KWh is decreased significantly for the presence of incentives in form of tax rebate quantifiable in about 0,02 €/KWh. Globally, incentives result remarkable because comport a reduction until the 30% of the cost for KWh and for an average user is quantifiable in 150-200 €/year. DH results more convenient then the other two systems present major initial investment. The presence of incentive indicate in: “Conto termico” for heat pump and solar collectors seems have a marginal rule with an overall amount of about 10% respect the initial investment. Is possible to declare without any doubt that Italian regulations cover an important role to make convenient DH and advantaging its respect other solution.

The combustion of straw like the wood biomass comport a great reduction of Co2 which compare with the other system result almost an order of magnitude less and confirms its important for the reduction of emission and degrowth the fossil fuels consumption.

For further details, interesting could be the study of emission that biomass systems haven in terms of dust and ashes in particular using straw. The data present in the literature are very limited and for straw boilers is not easy predictable. In this project the only precaution that has been adopted regard the distance from the buildings. Boiler house has been positioned as far as possible with a distant quantifiable in about 100 m form the nearest Buildings. Otherwise, in my opinion interesting may be the study of small cogeneration systems connect with a small area like in this project or lower, in order to compare the benefit and the final cost for KWh with the biomass system.

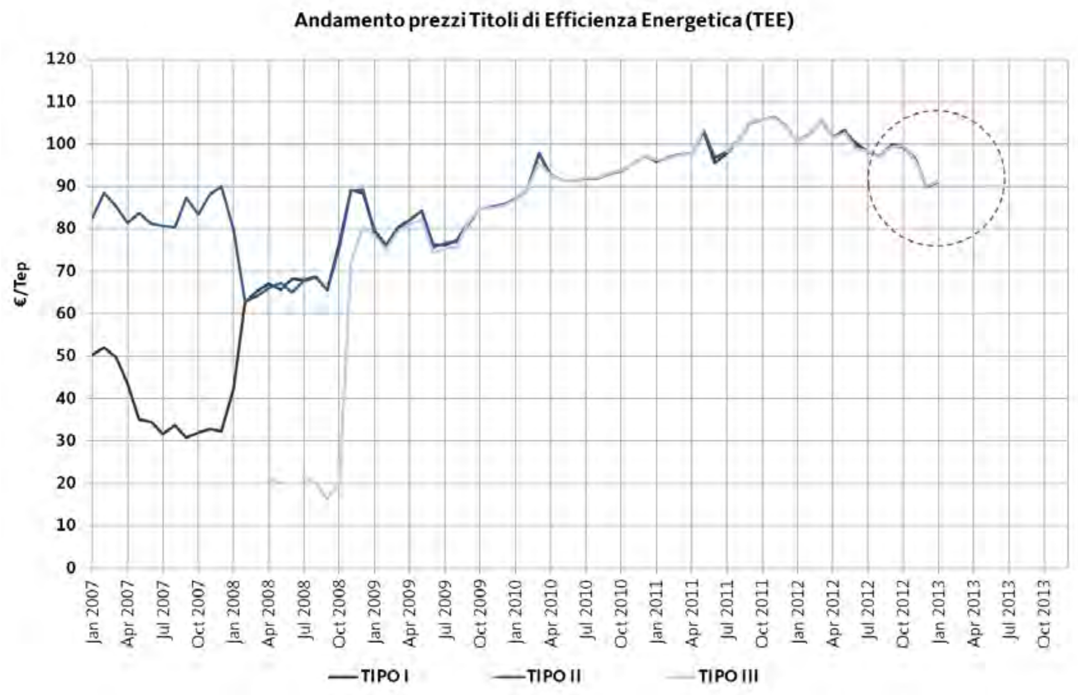
Appendix

A.1 White certificates: value and calculation method

The method to evaluate the number of TEP saving is report in technical 22T present in the Annex A to ENN 9/11.

Regulation defines that DH system can receive TEE for a period of 5 years but the number of certificated emitted consider the entire life which is consider of 20 years. Regulation introduce a factor τ that is called coefficient of duration and consider that incentives are disbursed in the first five years and then the amount is decrease to consider the major value of money respect an equally distribution in 20 years. For DH τ is equal to 3,66 and multiply the yearly value of TOE. Moreover is define a coefficient included between 0 and 1 that multiply the yearly TEP, for DH this value is equal to 1.

TEE have a variable price because due to the negotiation. The trend is reported in the graphic for typology I, II and III. Every typology is referred to a different technology. In this case will be emitted TEE of kind II



A.2 Economic indices

The evaluation of investment is made using some financial parameter and determinate if the sales price are acceptable for the company. Three different economic indicator will be use:

- NPV: net present value
- IRR, internal rate of return
- Payback period

Net present value

This indicator considers the idea that an investment is convenient only if the benefits are more than the initial rescore used. The formula of NPV considers the entrance flux in different years giving different value which depend to the year in which these fluxes append. It is considered an index to actualize the profit append in different years. Mathematical expression is:

$$NPV = -C_o + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t}$$

C_o: Initial investment

C_t: Net cash flow at time t

i: Discount rate

n : Duration of valuation

Internal rate of return

Internal rate of return is calculated resolving the equation of NPV and imposing that its value is equal to zero. The new incognita is now the value of i that indicate the return of invested capital

$$-C_o + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} = 0$$

Payback period
Is the time necessary to cover all the initial cost and starting to have benefits from the investment.

A.3 Incentives in according to "Conto Termico"

The plant that you want to realised can benefit of incentive in according with the "DM 28 December 2012" usually calls "Conto termico". Particular incentive are present for heat pump and solar collector. The amount and duration of incentives dependsto the system typology and size.

Heat pump
Incentives are given in function of the estimates production of energy evaluates consider the heat pump size and the climatic zone. Heat is calculated:

$$Q_u = P_n * Q_{uf}$$

Q_u : Heat produce from the plant [KWht]

P_n: Heat pump nominal power [KW]

Q_{uf}: Coefficient that depends from the climatic zone [KWh/year]

Only a part of this energy can benefit the incentive and this depends from the COP of the heat pump or rather to the real capacity to save primary energy.

$$E_i = Q_u * (1 - \frac{1}{COP})$$

E_i: Energy that can benefit of incentive [KWht]

$$I_a = E_I * C_i$$

I_a : Yearly incentive [€]

C_i: Value coefficient [€/KWht]

Moreover, heat pump must respect a minimum value of COP for fixed work conditions. Minimum values are reported in "allegato II DM 28 dicembre 2012" and depends to the size of heat pump and typology. With air/water heat pump values are:

Power	External air temperature	Flow and return temperature	COP
<35	6°C dry bulb 7°C wet bulb	30-35	3,8 2,7 in zone E,F
P<35	6°C dry bulb 7°C wet bulb	30-35	4,1 2,7 in zone E,F

Values of coefficients are different for the two cases. For the smaller is 0,055€/KWht with a duration of 2 years. The other heat pump have a coefficient of 0,018€/KWt for 5 years. In climatic zone E is indicated a value of Q_{uf}= 1700 KWht/KW.

	Heat pump nominal power	COP	€/year	Duration [year]
Binding 19	29,1	4,11	2058	2
Building 38	52,5	4,13	1217	5

Solar collectors

Incentives are given proportional to the gross surface of panels. Regulation makes a distinction between plant with a surface major or minor of 50 mq. Plant with lower dimension received an incentive for two years, the other for five but with a lower value of €/mq. Another distinction is made depending to the typology of plant: solar collectors, solar collectors with solar cooling and concentrating solar system. For this situation the duration of incentive is 2 years with a contribute of 170€/mq.

$$I_y = C_i * S_g$$

I_y: Yearly incentive

C_i: Value coefficient in €/mq

S_g : Gross surface mq

Yearly incentive for the two solution are:

	Area [m^2]	€/year	Duration [year]
Binding 19	6,96	1183	2
Building 38	23,2	3944	2

A.4 UNI 9182, DHW consumption

The consumption of DHW is calculated with the UNI 9182, which explain to calculate the consumption during a peak period.

For residential utilities is consider a peak period duration of 2 hours. In this period must be calculated the maximal possible consumption consider the number of flat and the number of installed sanitary appliances. It is consider that for every flat are install one of: shower, sink, kitchen sink and bidet. Each one of these appliances are consider use two times for every hour and then four times in the peak period. Hot water consumption for every single use is show in the table:

Table 73: Hot water consumption for every appliance

Appliances	Consumption at 40°C [l]
Shower	60
Sink	12
Kitchen sink	20
bidet	10

Consumption in l/h is calculated as:

$$Q = \left(\sum \frac{q_i * N_i}{d_i} \right) * f_1 * f_2 * f_3$$

q_i = water consumption for every appliance

N_i = number of installed unit

d_i = duration consumption time

f_1: Contemporary factor

f_2 : Number of room factor

f_3: Lifestyle factor

Contemporary factor depends to the number of flats while lifestyle is consider equal to one, considering normal condition life. Number of room is consider 4 and the correspond factor is 1.

Value for the two building are report in the table

Table 74: Hot water consumption during the peak period

Building	N*19	N°38
Flat	6	31
Contemporary factor	0,56	0,35
Total value [l/h]	752	2430

DHW production is realised with storage and this permit to reduce the necessary power. Tank dimension and necessary power are dimension with the follow equation.

$$V = \frac{Q * d_p * (t_f - t_c)}{d_p + p_r} * \frac{p_r}{t_t - t_c}$$

$$P = \frac{Q * d_p * (t_f - t_c)}{d_p + P_r}$$

d_p : Peak period duration

p_r: preheating time

t_f: Water flow temperature

t_c: Initial temperature

t_t: Water temperature in the tank

A.5 Grid structure

Pipeline network and the connection with users represent one of the major cost in the construction of district heating system as an initial cost, that for manage due to the energy losses. The grid consist of many component like:

- Tubes
- Valves
- Blocked section and compensator
- Pumping stations
- Heat interface units
- Expansion vessel

There are substantially two type of grid for district heating: open or closed system. The first case is very uncommon but there are plants in which is present only the flow tubes without return. Water is rejected in the environment after the transferring of energy. Almost all grid present two pipes and the fluid comes back to the boiler house and it is heat up again. There are many typologies of grid configurations but everyone have different vantage and disadvantage influence from: plant dimension, type of utilities, necessary of reliability and other factors. The three common configuration are:

- Tree structure: is typical use in great systems and represent the cheapest and easier solution
- Ring structure: permit to feed the utilities from two direction and guarantee more reliability in case of damage or maintenance. It may use to feed particular structure like hospital. The flux of water is guarantee although the line is interrupt because fluid can arrives from the opposite side
- Mesh structure: is used when the density of utilities is high. Mesh constitute a dense grid of pipe connecting together.

In presence of large grid the structure, assume a higher grade of complexity. This is the case when heat is provide from different type of utilities or when heat is produced by different companies in different systems. In this situation the grid is divided in many parts using heat exchange and making every part hydraulic and thermal independent. Pipeline are then composed from many level with different temperatures and pressures. In North-Europe there are big DH plants and some company sell their heat to the DH manager and the production stations are completely separate for the presence of exchange that separate boiler or other system from the grid. The production temperature and pressure in the grid is different from the condition present in the production units. In main line is convenient to have high temperature using superheated water, because the diameter of pipes is reduced and is possible to provide energy with a higher temperature for user that requires that. For residential utilities, superheated water

is usually more problematic, and another level is created, and residential utilities can receive water at lower pressure and temperature.
There are many aspects to design and variable to consider. For example the temperature of the water, the diameter of pipeline and the best configuration of the grid. The variables that is necessary to consider are firstly the flaw and return temperature, the losses of heat and the pumping cost. All this aspect must be analysed to design the pipeline network.

A.5.1 Types of tubes

Bonded tubes

The most common solution to realize DH pipeline is to use pre-insulated tubes. These tubes present a sandwich structure and they are composed from many layers and materials. Main tubes is in steel and it is covered with polyurethane foam and another tube in high-density polyethylene (HDPE). Inside foam are present one or more cables which function is to detected water losses and humidity infiltrations inside the insulation layer. These tubes are called "bonded" (specify in EN253), because the three components are assembly in a compact structure without the possibility to have axial slips. This characteristic is due to the particular productive process define in the mentioned regulation. One of the most important characteristics describe in this regulation is the resistance to shear stress that influence the duration of tubes. Shear stresses are generated with the friction with the ground, when tubes are buried. Tangential forces are generate inside the insulation layer that attempt to separate the three layer.
The most common material used in DH tubes is carbon steel. These tubes have to satisfy strict conformity monitoring and have test certificate in according with the EN 10204. Typically, tubes are welded and realise in Fe360, non- welded tubes are usually more expensive. Steel presents some alternative for medium-small diameter but are not common. The most important are copper and PEX (cross-linked polyethylene). Copper represents the best solution but the price is high. The main vantages of this material are the good ductility that permit a well compensation of dilatations and its behavior to corrosion but its high price make this solution unrealizable.

PEX is the material that present the best corrosion resistance. It is not welded and the junctions are made with steel coupling pressed at the end of tubes. The main problems for PEX are due to the permeability of water and oxygen that increase with temperature. For these reasons it is not completely compatible with DH but nowadays it finds many uses in DH cooling . Oxygen permeability can be resolve with particular barrier positioned inside the pipe. This phenomenon increase the quantity of oxygen present in the water and bring damage effect to the other steel component. Water permeability is a phenomenal that take place in the opposite direction. When tubes work at high temperature (major of 70°C) water through the tube like steam in great quantity. This phenomenon is not dangerous for the tube but for the insulation which is corroded from water. For this reason PEX tubes are not common in DH pipeline and price are also higher than steel. A special solution to resolve steam flux problems is the position of an aluminum layer in the internal side of tube. Water temperature until 95°C can be reached but these tubes are produces only for small diameter (lower than DN 200).

Tubes need an insulation layer to reduce thermal losses. This layer is composed by polyurethane foam. Coefficient of thermal conductivity depend for all three factor that characterized thermal exchange: conductivity, convention and radiation. The structure of polyurethane presents infect cavity with gas. The typology of gas trapped in cavities is important to determinate ʎ value because influence the radiation and convective phenomenon. ʎ value is always included between 0,027W/m*K and 0,033W/m*K but the real value increases with the passage of time because the original gas, usually Cyclopentane or carbon dioxide are naturally replaced by oxygen that result less performant.

Foam have a density about 60-80 Kg/m^3 and represents the weakest part of tube. The external part of tubes is cover by polyethylene layer that form an external tube with good rigidity. This tube has two important function; the first is in realization phase of the tube and it is indispensable when the polyurethane expand creating a close volume between main and this second tube. Moreover, during the life of tubes, when it enters in service, protect the foam from humidity and impact with ground.

Pre-insulated tubes are usually provide in bars long 6-12-16-24 meters and the end are not covered by insulation layer to permit the welded when pipeline are installed.

The not insulation portion has a standard length of 150 mm. Thickness of insulation layers are normally standardization and commonly manufactures use three different solution: standard, plus and plus plus insulation, respectively in crescent order of thickness.
Pre insulated tubes have a cycle life that depends from the working temperature. The polyurethane foam infect decrease its mechanical property with heat and time. For these reasons has been introduced laboratory tests to determinate the life of these materials. These tests are explained in EN 253-Annex C and specify the test method. Regulation order to keep the foam at high temperature for short time and through correlation real life of tubes is estimated.
With the passage of time mechanical propriety of foam drops and tube is consider in well condition until the foam is able to support shear stress of 0,13Mpa. With our technology, the best foam that now is produced can resist for 30 years at the temperature of 140-150°C. Pipes that work under110-120°C have an estimated life cycle of 50 years.
Some problems are present in pipelines that work with extremely high temperature, for example in steam system where temperature can reach value of 180°C. Different solution are necessary and the technology presents in the market provide two different alternative. One of these is represented from pre-insulated tube with a calcium silicate layer pones between steel tubes and polyurethane foam. The layer reduce the temperature that interest the foam because another thermal resisted is introduce. The solution present some problem of thermal expansion, the system is no longer bonded type and the dilatations can't be controlled. The second solution is represented by "steel in steel" tube. Main tubes is covered with a layer of stone wool and inserts in another steel tube cover with PE. Between the two tubes is created the void to increase thermal resistance. PE tube function is only to protect steel tube. This solution guarantee well reliability but present high installation cost.
An important phenomenon to consider is the thermal expansion when water temperature changes. Tubes changes their length when the temperature of carry water changes. The structure of bounded tubes transmits the change of length at the external HDPE tube which is in contact with the ground and generating frictions force. Considering a single free tube, not connect with other tubes, this force block

the movement creating internal tension. A more detail analysis is necessary to understand the behavior of buried tubes that is completely different to a normal tubes installed in air. The presence of frictions make the situation more critical and tubes can be stressed despite its end are free to move. The friction forces present in a buried tubes depends to the diameter, deep of buried and ground density.
The expression for unit of length is:

$$F_a = \frac{1 + K_0}{2} \sigma_v * \mu * \pi * D + \mu * G$$

Where:

D = external diameter of HDPE tube

K_0= coefficient of ground compact ($K_0 \cong 0{,}5$)

μ = friction coefficient

G = weight of tube full of water

σ_v = ground stress at level of the tubes axis due to the deep of buried = $\rho * g * (h_0 + \frac{D}{2})$, ρ = ground density , h_0= deep of buried .

Flexible tubes
Another solution for small diameter (<DN150) is represented by flexible tubes. This tubes present many advantages making the laying easier and cheaper than normal solution for two reason. The first is the possibility to realize convoluted grid crossing the natural obstacles. For example, tubes DN50 have a radius of curve about 1 meter. Second advantage regard the length of this tubes that can be realized in according with the customer needs. Tubes long some hundred meter can be realized and permit to save time in the lying. Using these tubes is also do not present the dilatation problem. For smaller diameter (<DN 50) there is a possibility to use a unique tubes with flow and return pipes. This solution result cheaper and easier to install and thermal losses are usually reduce. Flexible tubes are realized in steel, copper or PEX.

A.5.2 Tubes link

Link point represents the weakest part of the pipeline and particular attention must have the process whom permit to connect pipes. These processes are explained in UNI 489 and including processes of welded and resetting insulation layer with muffle. Welded process must consider the high stress that the pipe suffers. The method used is TIG, electric arc in modify atmosphere and the welder must be qualified. The continuity of the cable for monitoring hydraulic losses must be replaced and after the resetting of insulation layer is one of the more delicate process and must be respected some requirements:

- Restoring the continuity of all material, insulation layer and HDPE layer
- Transmit the stress generated in the insulation and protection layer
- Guarantee the waterproof for almost 30 years with a temperature of 120°C

There are many way to realize junctions. The first element to analyze is the muffle, which represent a cover to apply in the connecting zone. Muffle creates a close volume that must be filled with insulant foam. There are many types of muffles:

- Steel muffle covers with HPDE, is composed with two half shell that are fix using bolts. Mastic is used to increase the grip with the HPDE tube.
- Heat shrink muffle, is made with HDPE or PEX. It is a sleeve that must be insert in one tubes before welding and after correctly positioned. The shrink process appends heating the end of part of sleeve and its reduction of diameter origin grip with the tube. Mechanical resistance can be exceed using heat shrink band to put over the sleeve.
- Open heat shrink muffle, the material is the same that in the previous case, but it is an open layer that must be attached to the tubes.

Heat shrink can also welder after the thermal process of shrink using conductive material between the sleeve and the HDPE tube that smelt the material.

The next step is restoring the insulation layer. Normally holes are lost in muffles and permit to put inside the insulant foam and they are closed after this process. Polyurethane foam must be the same or with better quality that in tubes because muffle represent a critical point.

The best typology depends in principal way to the tube diameter, the number of thermal cycle, deep of buried, and the composition of ground.
In flexible tubes, the link process is considerably easier and faster. As said, the length of these tubes is realized apposite for every situation and this limits the number of junction. Only the main tubes are connected and the insulant layer can be applied without great precaution. Normally the manufactures design a particular system to connect the end without welder process but using special fittings connect with plastic deformation and using particular tools.

A.5.3 Broken localization system

Insulation tubes may have problems in junction between two ends or due to excavations made near them that can damage tubes. When HDPE tubes is damage, water infiltrations can ruin the polyurethane foam or corrode the steel pipe. Water losses represent also a cost because the thermal losses are increased. For these reasons is common to installation a monitoring system that report immediately eventually problems. In the past when pre-insulated tubes wans't used, tubes was positioned in concrete channel and the losses can be localized using thermal sensor. This was easier because hot water remained trapped in the channel but now, new pre-insulated pipes are positioned directly in the ground and this method does not permit to detect thermal losses because water is absorbed in the ground. Different methods have been developed, the more common are: method of pulses reflection and measure of resistance.

Method of pulses reflection
Method of pulses reflection has been the first introduced for losses localizations in pre-insulated tubes. Two copper rods without insulant layer are positioned inside the polyurethane layers. The cables have a section of 1,5 mm^2 and with steel tubes constitutes a system like a coaxial cables. Copper rods represent the circuit, foam the dielectric and tubes is the grounding system. Two copper rods are parallel to the tubes and connect with a control unit. In the end of pipe, the two rods make a short circuit. Foam, that represent dielectric have a high resistance, for example 200Ω. When water losses or infiltrations are present, the resistance between rods and pipe drop, and the units can measure a reflection time of send signal. Units emits codified

impulse with low voltage (3 V) and in case of damage the reflection time can be measured and damage position calculated. The precision of the measure is about 0,5 meter using 6000 pulse. When new pipe are added to the main line, new rods can be connected with the rods present in main tubes. The connection of rods in presence of branch or in the conjunction point between two tubes are made with connector and after welded.

Method of resistance measure

This method establish that two rods are positioned parallel to the tube. The first rod is insulated and presents a high resistance, more then 5Ω/m. This rod is made in NiCr and its insulant layer present hole a fixed and constant distance. Return rod is a normal insulated copper and present a low resistance, about 0,036 Ω/m . Two rods make a short circuit at the end of pipelines. Control units measure the resistance between NiCr rod and tubes. Copper rod is only a control system to measure the total NiCr rod resistance. In case of damage, the presence of humidity decrease the resistance of polyurethane. Unit measure the new value of resistance that depend only to the damage position because NiCr rod present a high resistance. System function like a voltage divider measuring the drop voltage present in the new circuit including steel tube.

Other method

Usually problem are located in welder point that represent the weaker party of system, a possible solution is to install sensor only in this part and connect them with a control unit. Sensors are positioned under the muffle and measure the humidity level.

A.5.4 Network laying

Pre-insulated pipes are usually buried and lay on a sand bed. Sand has two important functions: save tubes integrity and guarantee uniform stick forces. Sand is optimal for its fine dimension and prevent that stone or other object with blunt shape can ruine the external tube.

Excavation and buried

There are two different systems to lay tubes: open excavation and blind bore. The second is necessary in some particular situations for example when is not possible to interrupt some service like train railway, important road or other situation in which there are some irremovable object on the ground level. The first solution is normally the more common and is made with the technique of trench excavation. This kind of works need some precisions steps and first of all the localizations of other underground service. In urban street are usually present pipes for natural gas, potable water, sewage system, electric grid and phone grid. It is necessary to delineate the correct position of all these systems and kept a minimum distance from each one of them. After that is possible to draw in the street the path where tubes will be place. The asphalt or other type of pavement must be cut, realizing a band no larger more than 40 cm respect the trench. The operation of cut is necessary to prevent that in excavation; asphalt can be ripped and to kept low the damage to the street. Asphalt is removed with hydraulic breakers. During excavation, trench is realized and in some cases, when the deep is more than 2 meters or the ground is soft is necessary to build temporary wall using wood panel. Trench width and depth depend to the tubes diameter and to the position of other service line, (an excavation more depth may be necessary to avoid the contact with other subservice). Normally the upper part of tube must be 600mm under soil level. Trench depth must consider a space for bed sand, tubes and a cover layer of 600mm. For these reasons, the total depth is important. The length have to guarantee a correct distance between flow and return tubes, from the excavation wall and guarantee a minim workspace. Near the welder area, the necessary length is major to permit the junction process.

Table 75: Length and depth in function of the diameter

DN tube	Length [m]	Depth [m]
40	O,70	1,20
50	0,85	1,25
65	0,85	1,25
80	0,90	1,35
100	0,95	1,40
125	1,05	1,55
150	1,10	1,60
200	1,23	1,65
250	1,40	1,70
300	1,50	1,75
350	1,60	1,80

400	1,70	1,90

Less depth can be used but is necessary to protect tubes from the load present up the ground level for example using concreate plates.

After excavation, tubes are posed on a bed of sand with 15-20 cm of thickness. The sand must be levelled and pressed. Tubes of small diameter can welded a twice outside the trench to make this process easier and after place in the correct position. Inside trench, the workspace is limited and tubes must be supported with mounds of sand to guarantee the space to make the welded in the bottom part of tube. It is necessary that sand bed presents a correct inclination, in this way is possible to empty tubes from some special valve if it will be necessary. After tubes lay, another layer of sand is positioned to realize a covering without dangerous object. The operation of filling happens using homogenous material to guarantee a good repartition of forces present above the ground level. The material is put in the trench in separate layer with a thickness of 20-25 cm and everyone is pressed with particular machines. This operation is necessary to avoid future ground subsiding and collapse of overlying asphalt. During all these operations the working zone must be delimits and indicated with specific signal. The dimension of this zone do not depend only to the tubes diameter but rather to the kind of machinery used, strictly connect with the trench depth rather than the width. The duration of the work depends usually to the diameter, type of ground and method of lay. Construction period depend also to the number of workers and machines present in working place. Inside the city usually is not possible to kept open long segment of excavation for reason due to the traffic and for not create insulate island inside the city making it difficult access to some buildings. Usually open excavation can not exceed 100 m and sometimes is decide to work contemporarily in more place along the same line.

Other the main trench, are necessary other work as wells and little rooms. These two constructions are realized in the presence of some particular point like valve, discharger and bled valves. Little room have great dimension and the component inside have to respect some limit like distance to the wall to guarantee a correct work space an free movement for employer that maneuver and regulate the line. Welles have limited dimension and can contain only the plant component without space for man. These components are for example valve utilize directly with the hands or using particular rod if the deep is remarkable. These structures are realized in concrete and can be made in worksite or buy pre-assembly.

Blind bore

The second solution to position pipes is the blind bore method or trenchless, (without excavation). The technique establish to realize two excavations where tubes segments start and end. Initially, in the excavation are positioned the necessary equipment to install pipes. For small diameters are used hydraulic cylinders that push the tubes and the hole is creating with the pressure generate from them. In other case is better to use auger drilling that are positioned in the head of tube. The cost of this method is usually higher but a correct economic analysis must consider many factor as the traffic problem that the normal method cause, the possibility of car crash, the necessity to make some changes to the preexistence service and other extra cost that change in every situation and often are not predictable.

A.5.5 Stress creates in tubes

Stresses which interest a pre-insulated buried tubes have two different origins: mechanical and thermal. The first is due to the pressure of water inside the tube and the second is caused by the difference of temperature between installation and work conditions that cause expansion and stress.

Mechanical stress

Mechanical stress can be represented in two different direction, tangential and longitudinal. The two stresses can be calculated using the theory of thin-walled tank because the relationship between radius and thickness is high and always more than 10, value consider in the hypothesis.

Tangential stress due to the pressure is given by:

$$\sigma_t = \frac{P * r_i}{t} \quad [MPa]$$

P = internal pressure [MPa]

r_i = internal radius [mm]

t= thickness [mm]

Longitudinal stress is related to σ_t and is calculated as:

$$\sigma_l = \frac{\sigma_t}{2} \quad [MPa]$$

The value of σ_l due to the internal pressure is always positive and involve in a traction stress.

Thermal stress

Tubes use in DH system are bonded and need some consideration to understand the behavior and what happened when they are buried. Phenomenon of thermal expansion for a tube which ends are blocked generate a stress portioned to the ΔT present between the service and installed temperature.

$$\sigma = \alpha * E * \Delta T$$

α = coefficient of thermal expansion [mm/m*°C]

E = Young's modulus [MPa]

The sing can be positive or negative and it depends if is consider a heat up or down process. Considering the installation in environment conditions, when tubes are heat up compression forces born. The real amount to these forces depends to the presence of block ends. If ends are free to move force can't born. There are two situation that can generate block section: one virtual and another with anchor systems. Second system is easier to explain and consist in system that block some point in tubes for technical reason and necessity. Virtual block section are imaginary constrains that generate high axial force. Moreover, movements in buried tubes are not free but control from the friction with sand. Considering a free buried tube, friction force depend to the distance from free ends. This force is distribute along the tube and offer an opposition to the thermal expansion force. When friction force begin major of expansion, force tube cannot expand and virtual blocks are generated. Consider only the presence of virtual block; value of stress depends only to the friction force and the distance to the end.

$$\sigma_t(l) = \frac{F_f * l}{S} \; [MPa]$$

F_f = friction force [N]

L = distance for the end [m]

S = resistance section [mm^2]

Thermal force tends to expand tubes, friction force blocks this movement. Equilibrium condition defines the length of maximal possible slide because the forces generate from the friction depends to the contact area between tubes and sand. The length necessary to have block section is defined as:

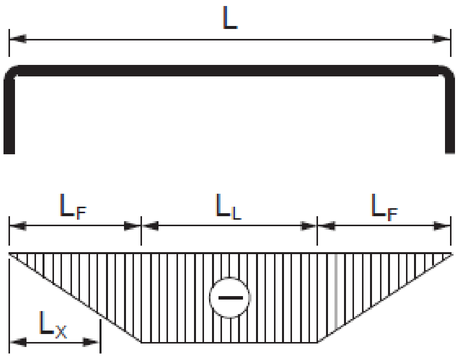
$$L = \frac{S * (\alpha * E * \Delta T) + (1/2 - \nu)\sigma_t}{F_a} \; [m]$$

ν = Poisson's coefficient

If the length of tubes exceed the double of this measure, the central zone remains block and stress is proportional to ΔT while the end are normally free to move. Normally, stress due to the internal pressure is treasurable and the previous equation can be simplified consider only the thermal contribute. This hypothesis is valid with small and medium diameter.

$$L = \frac{S * (\alpha * E * \Delta T)}{F_a} \quad [m]$$

Table 76: Normal stress generates along the tube



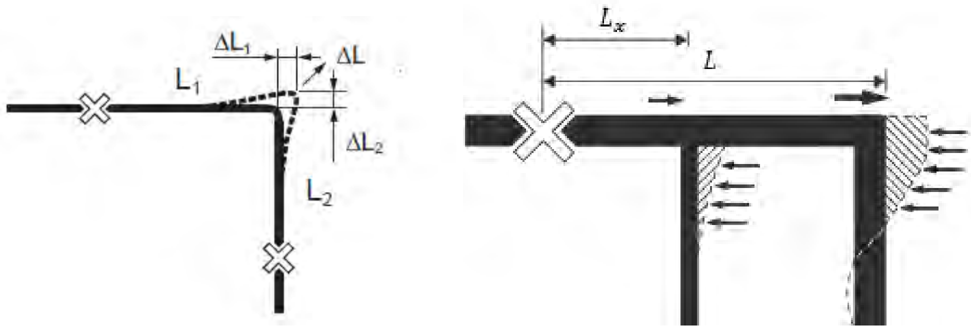
Bends need to be free to move and avoid the born of force due to the presence of sand. The expansions of tubes in these points is important to dimension the foam pads that adsorb dilatation producing treasurable reaction force. The dilatation in a generic section distant L_x from the virtual anchor is:

$$\Delta L_x = L_x * \alpha * \Delta T - \frac{F * L_x^2}{2 * S * E}$$

The expansion in both side will result in radial movement at the bend. The radial movement for 90°C bend can be calculated as:

$$\Delta L = \sqrt[2]{\Delta L_1^2 + \Delta L_2^2}$$

Figure 17: Movement of bends and brunch points



The calculation of dilatations near every branch must be known to avoid stress in the connection points. Branch pipe follow the movement of main line and this expansion involve in lateral movement that is possible calculate as:

$$\Delta L_x = L_x * \alpha * \Delta T - \frac{F * (2 * L - L_t) * L_t}{2 * E * S} \quad [m]$$

Foam pads must be set also in this critical point.

A.5.6 Installation techniques

In DH pipeline, the temperature of fluid is usually included between 90-140 °C, depending to the adopted solution. The temperature presents when tubes are installed is fundamental to consider dilatations problem because defines the maximal jump of temperature. In Italy, installation conditions are usually included from 0°C in winter to 35°C in summer. Thermal gradient of 70-120°C is then normally present considering an average temperature of 20°C.

The effect of this gradient depends to the material that usually is Fe360 characterized by:

$$\alpha = 1{,}2 * 10^{-5} \, °C^{-1}$$

$$E = 2{,}1 * 10^{5} \frac{N}{mm^2}$$

Considering a block tube, stress due to the friction, with ΔT =120°C, is about 300 Mpa higher than the lower yield strength of 235 Mpa for this steel. This value is not eligible and is necessary keep it down respecting a security coefficient. A recommended value is about 150 Mpa. There are many solutions to decrease tube stress.

Thermal pretension

Thermal pretension permits to reduce the stress present in the working condition realizing the plant with an intermediate temperature between ground and working condition. Tubes are welded after heating, for example at 60 °C. The condition of null stress is now at this temperature. When the tubes are cooled down it will be in traction and when they are in work condition will be compressed but the tension will be lower because due only a half of the original gradient. This solution result more expensive than the other because is necessary to keep open the excavation for long period and distance and normally comport a lot of problem in the urban areas. This solution present moreover high cost to heat up tubes.

Expansion curves and compensators

These solutions limit the straight portion of tubes and keep down the maximum possible value of stress. This is possible because completely block section are delete. Tubes dilatation can be distributed equally with a deformation in the zone where the rigidity is lower. Considering an imaginary point in the middle of straight portion the maximum stress is there and can be calculated. Expansion curve is realized through curve insert in the pipe forming U or Z shape of tubes.

This technique is the most common but comport more installation and working cost because the number of curve is increase and also the total pipe length with more hydraulic and thermal losses. These problems are more evidence in tubes with great diameter because bigger compensators are need, which sometimes are hardly realizable in the narrow urban street.

An alternative to use curve is the utilization of artificial compensators but this result more expensive and particular attention need the behavior to the fatigued life cycle.

Thermal pretension with one-use compensator

This method is mix between the previous two. Tube is pretension but it happens with a close excavation. This is possible using a particular compensator that function only one time, when the line is heat up for the first time. In this situation when the tube reach a default temperature and then a certain expansion, the compensators are welded and stress will be zero at this intermediate temperature like in the first solution explained. When the temperature is modify will born stress but its value will be low because due only to half temperature gradient. This method is the more common particularly whit the main line with large diameter. The only disadvantage is the necessity to lose many point of excavation open or realize new tranches to weld the compensators.

Cold installation

Cold installation is the easier but also the more dangerous technique. Tubes are buried without precautions. In every thermal cycle, tubes can reach an axial stress of 300 Mpa. Sometimes is possible to use steel with higher yield strength or accept the idea to work in plastic ranges. Curves and other component result more stressed and they must be designed with more cure. Tubes suffer of instability problem and is not possible and dangerous to make other excavation near tubes because equilibrium and stability are guarantee only from the ground. For these reasons the technique is hardly use in urban area when the water temperature is more than 90°C and the plasticization is evidence. In urban area the realization of new trench in the ground are common and can destroy the equilibrium presence in the ground.

A.5.8 Connection with users

Connection with users is made with units installed in every building. Units are installed one for every building or in every flat. The configuration is the same with central heating or private boilers. Normally, units are installed in pre-exiting boiler rooms because for boilers is no longer necessary and this result the natural and easier solution. However, the presence of units is safer then boilers and the room in which they are installed can hosting other subservices. Units do not present combustion process and inflammable substance and fewer prescriptions are necessary.

There are two type of methods, which is possible to connect single utilities with DH grid: directly and indirectly connection.

Directly connection

Directly connection establish that the water present in DH grid feeds directly the user. This solution results cheaper respect the indirectly connection but presents some disadvantages like the necessity to have the same pressure in DH and domestic plant. However, there are some advantages besides the initial lower cost and the possibility to provide water with lower temperature because utilities are directly connect with the grid and the heat exchanger is omitted. Temperature is 15-20° C lower respect indirectly connection in the flow and return. This is desirable with geothermal or heat pumps system.

The element that formally separates the two circuits is the three way-valve which mix the water in secondary circuit with the water provides and regulate the temperature. An apparatus kept the pressure on the three way-valve constant despite it change in DH plant. The absence of heat exchanger make impossible to have high pressure in the primary line, usually under six bar, max value sustainable in domestic plant. This fact comports the necessity to have low hydraulic losses in main line that involves in bigger diameter of pipes. This solution is hardly applicable when there are gradient in the area and pressure different are accentuated.

Indirectly connection

Indirectly connection establish that DH grid and utilities realized two different circuits. Heat interface unit is the element that connect district heating tubes with the utilities. This interface is composed principally with a plate heat exchange and other control device and safety. Utilities are hydraulically separated to the main grid to guarantee two different levels of pressure and more security. The pressure present in the grid is usually high because district heating have to supply heat in a large area with long extension of pipeline and high hydraulic losses. For this reason, result necessary to have high value of pressure almost in the section closed to the pumping station. This is increased when the soil is not level and static pressure have great difference of altitude in a small area. Pressure in main grid can be reached the value of 15-20 bar or higher while domestic utilities pressure usually not exceed 2 bar. Using heat exchanges are realized two different environments and for example in case of damage in the user plant the water that can flow out to the plant is limited. Heat interface units present in the market have differents configuration and dimension. Some units present only one exchange, and DWH is prepared in another system like tank with heating coil. In other case are present two exchanges, one for heating and one for DHW. The range of dimensions of these units is very wide and cover power from few KW to 5000-6000 KW for great utilities like hospital or factories.

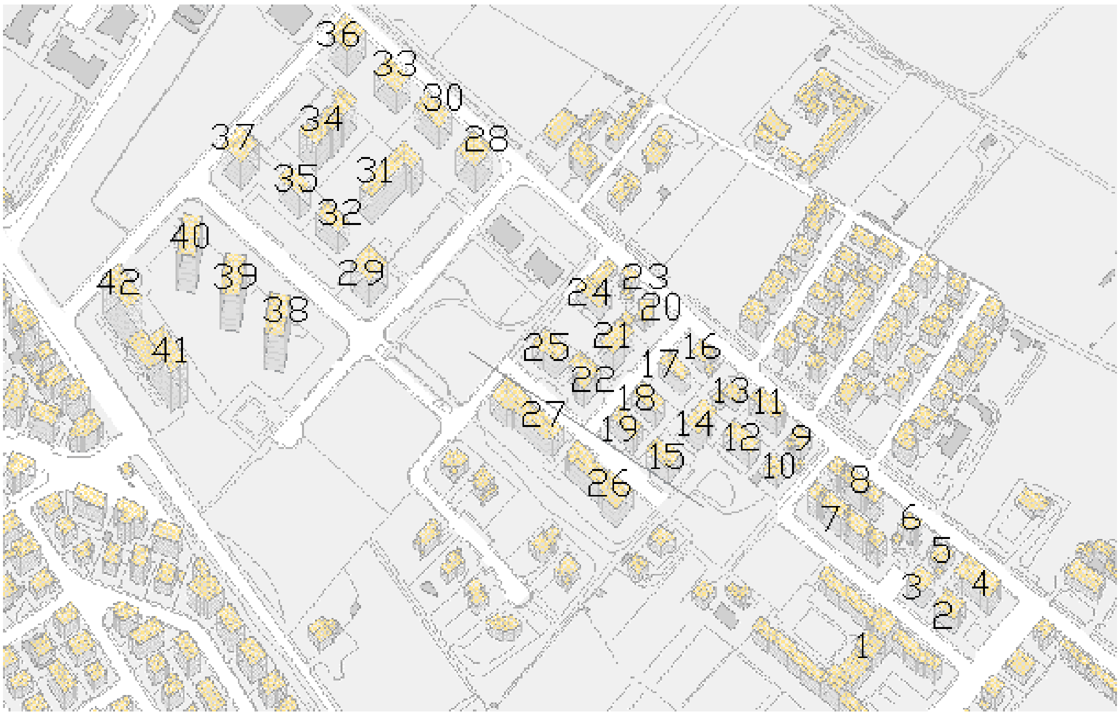
A.6 Politics and strategy for the heat sell price

Cost of heat provides from DH depends to the politics adopted from the company that manage the system. In Italy, the cost for KWht is really variable and it depends to external factor like the presence of natural gas pipes. The presence of gas grid tends to kept low the cost of heat because, in the place where the only other solution is the gas oil, the cost to produce heat is sensibly higher. The real phenomenon that permit at the company to increase their profits is usually given by switch costs, that are present when you want to change heating system, for example eliminate the heat exchange and install a new gas boiler. Some company applies penalty when you want to give up from DH connection with imports include between 400-1000 €. Switch costs permit to increase the cost of energy that in some case result higher respect price of natural gas.

The realisation of new plant or the expansion of pretexting needs politics of market penetration because DH plant cause high initial cost and is necessary to increase fast the number of user to cover quickly the initial cost. In new areas, the politics is clearly and the purpose for DH manager is to convince the major number of user in a short period. This is obtained using low cost of energy and economic contributes to cover part of the initial cost with the result to decrease the cost for switch-cost between old and DH system. Amount of contribute can reach 50-100% of the connection cost. These incentives sometimes are given when is necessary to replace the flat units. This push the user to maintain the DH connection despite the economic convenience is no so evidence. In areas where DH is consolidate, the best solution for manager would be to have different price for old and new customers but this is hardly realisable.

The price of heat is establish in according with two different system: monomial and binomial tariffs. Monomial tariffs establish a price for every KWht directly proportional to the overall consumption. Binomial tariffs expected a fixed cost and another part proportional to the real consumption. Monomial structure comport usually a major cost for KWht for the absence of fix cost and invites people to keep down the consumption and favorites the energy saving. In binomial tariffs, the reduction of consumption is not proportional to the total price and tempt to keep high the consumption. Binomial tariffs are preferable for DH company because respect better the real cost supported in the heat production: fixed cost, amortization, maintenance and variable cost of fuels. Reduced cost for KWht involve in major consumption and increasing the profitability. Binomial tariffs result instead more complex to understand and for the final customer is more difficult to catch the real advantages and the real price for KWht. In Italy price of natural gas is calculated with monomial tariffs and using the same method for DH is easier to make comparison. Companies that used binomial tariffs adopt a fix cost that usually do not exceed the 30% of the entire price, to avoid the inconvenience due to the binomial tariffs for the customers. These tariffs are normally adopted in plant with great dimension and usually is possible to choose between one or other system. In small plant, feed by biomass monomial tariffs are normally the only present.

A.7 Numbering of the Buildings in the project



Thanks

I would like to thank my supervisor, the professor Michele De Carli that gave me the possibility to make this work at the VGTU (Vilnius Gediminas Technical University) with the Erasmus+ program. The professor Artur Rogoza who helped me during the time that I passed abroad. I want to thank my family that permitted me to study in all these years and Giulia, my girlfriend who have always supported me even during my Erasmus experience. I can’t forget the friends of Murialdo, the college in which I lived for 5 years: Filippo, Giovanni, Fabio, Andrea, Matteo, Luca, Marco, Gioxy, Stefan and Davide, my roommate for all this time and our nights spent to discuss about everything for the happiness of our neighbours. I will never forget my friend, classmate and mate of college Abedin with whom I prepared and suffered for all the exams done in these years. I want to thanks all other my friends to whom I have subtracted time living in Padova

Reference

ENEA (National agency for new technologies) :"*Biomasse e bioenergia"* July 2011

ITABIA (Italian Association Biomass): "*I traguardi della bioenergia in Italia*" 2008

National autority for electricity and natural gas: "Relazione annuale sullo stato dei servizi e attività svolta" 31 march 2013

Ministro dello sviluppo economico: "Statistiche ed analisi energetiche minerarie" 2014

AIRU (Associazione Italiana Riscaldamento Urbano), "*Il riscaldamento urbano*" Annuario 2012

Autorità dell'energia "*Indagine conoscitiva sul settore del teleriscaldamento*" 2012

Danish energy agency: "*Energy in Denmark*" 2012

INBIOM, Innovation network of biomass "*Straw to energy*" Status, technology and innovation in Danmark, 2011

Regione Veneto: "*Il settore agricolo regionale*", Febbraio 2011

EUROFORAGGI societa agricola srl "*Pellet di paglia e stocchi di mais presso Baggioni Group*"

Ministero politiche agricole e forestali "*Annuario dell'agricoltura in Italia*" 2011

ITABIA, Report 2008 "*I traguardi delle bioenergia in Italia*"

Vincenzo Corrado, Ilaria Ballarini, Stefano Paolo Corgnati: "*Building Typology Brochure-Italy*" 2014

Marco Camussi, A2A "*Costruire città sostenibili*", Milano 17 marzo 2010

Ulrike Jordan, Klaus Vajen: "*Realistic domestic hot-water profiles in different time scales*" 2001

LARETER " *Pre insulated pipes and fittings PVC-PE100*"

David Palmer, Ian Tubby, Geoff Hogan and Will Rolls "*Biomass Heating: a guide to medium scale wood chip and wood pellet system"*

Datasheet: " *Reka push grate boiler type HKRST*"

The Centre of Biomass technology:" *Straw for energy production*", 1998

Regione Lombardia: "*Manuale per la posa razionale di reti tecnologiche nel sottosuolo*", 2007

Rossato Group: “*Pompe di calore aria acqua ad alta efficienza*”.

CASAFLEX: “Tubazione *specifica per allacci di utenza*”

Eros Tassi: “*Soluzioni per la produzione e la distribuzione dell’energia termica in un centro urbano:* sistemi di distribuzione”,2004

Mirco Bonaso: *“ Fiscalità nella gestione di un impianto di teleriscaldamento a biomassa”*

Regione Abruzzo: *“Listino impianti meccanici”* 2014

.