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Development possibilities in municipal energy sector in Russia

VELI-MATTI MÄKELÄ

ePOOKI 10/2016 – THE PUBLICATIONS OF RESEARCH AND DEVELOPMENT WORK OF OULU UNIVERSITY OF APPLIED SCIENCES

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Summary

It is important to analyse and optimise the whole energy system of municipality level or regional level or maybe on national level to achieve maximum energy efficiency and minimum environmental pollution and stress. District heating is only a part of the energy system and it is impossible to achieve remarkable results by developing or optimising district heating independently. Main savings and improvements can be achieved in overall system level optimisation of electricity and heat production and delivering system.

Improvement of energy efficiency and municipal energy systems in Russia has been a goal for a number of different development projects. Most of the projects have been aimed to achieve better energy efficiency with some technical improvements. But the energy efficiency and quality of energy services has improved very little if at all. It is essential to understand the importance of the whole energy system and system level planning. Most of the energy losses and lowered efficiency as well as poor quality have been caused in system level. It is impossible to achieve the good results with increased quality of some independent equipment. This is because most of the losses and inefficiency is caused on system level planning errors and poor quality systems.

The overall efficiency in municipal energy systems is very high in Finland. District heating is an important part of the municipal or regional energy system. Almost 50 % of space heating in Finland is made by district heating. The share of combined heat and power production increased already during 1970s and 1980s when district heating in largest cities in Finland was growing very fast. Suitable amount of heat load is an essential requirement for combined heat and power production. In Finland about 75 % of district heat is produced in combined heat and power production plants for several years. Combined heat and power production also helps to decrease CO_2 emissions in energy sector.

Having high quality norms and recommendations as well as high quality components does not guarantee high quality, reliability and a long lasting system. First, there is a need for a new design philosophy and for the optimisation of heat production. After that, there is a huge need for quality control systems in the Russian district heating. Particularly in the district heating network, this kind of system is needed. There will be a need for a quality management system in the norm or in other higher levels. Some parts of the quality system can be organized by the manufacturers or the district heating company's own quality management system. In some parts, there will be a need for independent quality inspections to be made by authorized organizations to give official and independent status.

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Terms and abbreviations

EU	European Union
DH	District Heating
CTP	Centralised Sub Station (from Russian language)
ITP	Individual Sub Station (from Russian language)
O&M	Operation and Maintenance
CHP	Combined Heat and Power
dhw	Domestic hot water, hot tap water
TC	Temperature controller (in connection schemes)
TE	Temperature sensor (el.) (in connection schemes)
PI	Pressure meter (indicator) (in connection schemes)
TI	Temperature meter (indicator) (in connection schemes)
P1	Pump number 1 etc. (in connection schemes)
KL	DH, district heating (in connection schemes)
LPG	Liquefied Petroleum Gas
EUH	Electrical under floor heating (in figures)
EV	Electrical heating in ventilation (in figures)
DP	Pressure difference (in figures)
EUH	Electric under floor heating (in figures)
EV	Electric heating in ventilation (in figures)
Pa	Pascal, pressure
bar	bar, pressure
kWh_e	Kilowatt hours electricity
MWh_{heat}	Megawatt hours heat
T_{flow}	Flow or supply (pipe / water) temperature
T_{return}	Return (pipe / water) temperature

Technical descriptions

Item	Description
CTP	Centralised Sub Station, servicing several buildings. CTP may include heat exchangers and temperature control devices. Not in Finland In Russia connection schemes of space heating and hot water may be direct or indirect as well as open or closed. Automation and control may …
ITP	Individual Sub Station is a substation for one building - Finnish substations are always indirect and closed individual substations with heat exchangers and building level automation and control devices - In Russia connection schemes of space heating and hot water may be direct or indirect as well as open or closed.
Open District Heating System	Water from DH net is used for domestic hot water
Closed District Heating System	DH water is separated from domestic hot water with heat exchanger
Direct District Heating System	Water from DH net flows in radiators for space heating or in other space heating equipment
Indirect District Heating System	Space heating network (radiator network) and DH network are separated with heat exchangers
CHP plant	Power plant designed to produce heat and power in one plant and in combined process. Heat can be used for industrial purposes or district heating or to both of them.

1 Background

The Europe 2020 strategy is about delivering growth that is: smart, through more effective investments in education, research and innovation; sustainable, thanks to a decisive move towards a low-carbon economy; and inclusive, with a strong emphasis on job creation and poverty reduction. The strategy is focused on five ambitious goals in the areas of employment, innovation, education, poverty reduction and climate/energy. [25]

To ensure that the Europe 2020 strategy delivers, a strong and effective system of economic governance has been set up to coordinate policy actions between the EU and national levels. The main goals in Climate change and energy sustainability category are: greenhouse gas emissions 20 % (or even 30 %, if the conditions are right) lower than 1990, 20 % of energy from renewables and 20 % increase in energy efficiency. [25]

DHTrain –project

DHTrain-Development of an efficient support network and operation model for the municipal energy sector is a two-year development and education project. The project is funded by Karelia ENPI CBC programme. The aim of the project is to improve energy efficiency in the Karelia region and to increase the use of local bioenergy resources in the district heating and in small-scale combined heat and power production plants. DHTrain also aims to increase the know-how of efficient energy production solutions.

Karelia ENPI CBC Programme

The Karelia ENPI CBC Programme is a cross-border cooperation programme implemented in the regions of Kainuu, North Karelia and Oulu in Finland and the republic of Karelia in Russia. The key objective of the programme is to increase wellbeing in the programme region with cross-border cooperation.

DHTrain project is co-funded by the European Union, the Russian Federation and the Republic of Finland.

Development of Energy Efficiency in Russian Development Projects

Improvement of energy efficiency and municipal energy systems in Russia has been a goal for a number of different development projects. These projects have been financed by several financiers and development agencies. Most of the projects have been aimed to achieve better energy efficiency with some technical improvements. But the energy efficiency and quality of energy services has improved very little if at all.

The main lesson to learn from previous work is to understand the importance of the whole energy system and system level design and planning [1]. Most of the energy losses and lowered efficiency as well as poor quality have been caused in system level. It is impossible to achieve the planned results with only some technical development steps i.e. increased quality of some independent equipment. This is because most of the losses and inefficiency is caused on system level planning errors and quality mistakes. Problems occur both in National level norms and local level decisions with partial optimisation.

1.1 Regional Energy System

To achieve real improvements in energy sector the whole municipal or regional energy systems need to be considered as one common unit or system, which has to be optimized all together. Partial optimization seldom leads to optimal solution.

Municipal or regional level technical sector or energy system quite often contains both district heating and electricity systems. Also a water delivery system is quite often a part of technical sector. Heat energy is used for different heating purposes for example in apartment buildings, offices, shops and industry. Electricity is used for living and industrial use as well as for different kinds of services. Water is not a real energy service but it is often part of the technical sector. Domestic hot water is included in the heating part of municipal energy system because of energy needed in hot water production. Water delivery system requires also electricity for example for pumping.

Municipal energy system should be designed to minimize primary energy consumption and optimize or maximize the efficiency of the whole energy system with optimal quality of energy services. Minimum primary energy consumption can be achieved only by system level i.e. regional or municipal level design and optimization. Partial optimization causes quite often significant increase of primary energy consumption. In this context primary energy is fuel consumption on regional level. There are also other parts in primary energy calculations like transportation of fuel.

Municipal or regional level energy production contains always electricity and heat energy and sometimes cooling energy. The best alternative to produce electricity and heat is optimized CHP production (see figure 1). Optimal CHP production requires also separate heat and electricity capacity for peak and spare production purposes.

In many cases it is possible to produce over 90 % of district heat in CHP plants, even if the capacity of CHP plant is about 50 % of the total heating capacity. The other 50 % of the capacity are the production peak plants. They produce about 5–10 % of annual energy demand.

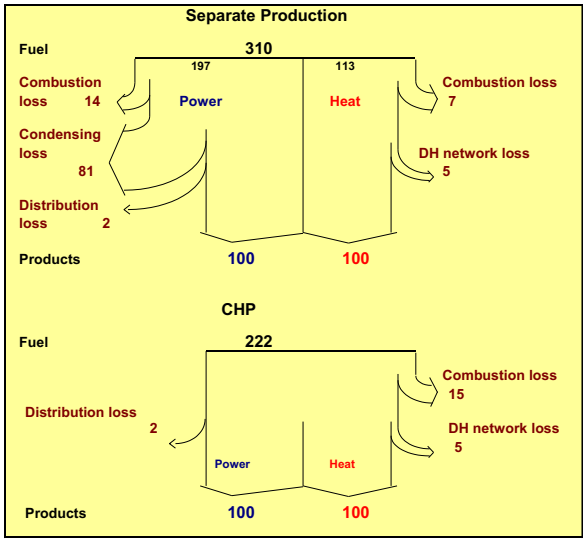


Figure 1: Sankey diagram of CHP and separate production [10]

In From the picture it can be seen that the production of 100 units of electric power and heat requires 310 units of fuel at efficiency of 64.5 %, when produced by ordinary gas fired combined cycle condensing power plants and boiler plants but only 222 units at efficiency of 90 %, if produced by a gas fired combined cycle CHP plant [10]. Saving of fuel (primary energy) is 88 units, which means about 30% savings of fuel to compare with separate production of electricity and district heat.

1.2 Relevance of the Project Related in to Russian System

The report “Bases for the recommendations for new norms in Russian district heating” points out several different kinds of technical problems and questions, which have arisen in the discussions and seminars during the implementation of the “RusNorms -project: Implementation of District Heating Norms in Russia – Evaluation and Piloting” (Mäkelä etc.) [1]

These technical problems need to be solved but the main interest should be in developing the whole energy system and system design. The main problem is the very low efficiency in municipal level energy systems.

Electricity and district heating production and whole energy business is normally separated in Russia so that it is impossible to plan and design the whole system in optimal way. In addition district heating is even separated in to several small independent networks so that the efficiency of district heating is also significantly lower than in Finland. The main reason of low overall efficiency is separation of electricity and heat production. Almost 50 % improvements can be achieved with optimal CHP production. Minor benefits are possible by optimization of district heating system only.

There will also be a need for new norms or recommendations for technical “requirements”. But those must not be developed without strong coordination with the system level norms development.

This paper starts with general issues like questions of overall efficiency of a communal energy system and some planning and design principles. Some examples from other European countries are presented. After that there are different chapters to describe development possibilities in different sectors of Russian district heating system like production, district heating network, customer connection, heat metering and district heating quality control system.

2 System Level Development

Municipal level and regional level optimal planning and design of energy system is the most important part of development of the local or regional energy system. The main goal must be the minimized use of primary energy and maximized overall efficiency in energy production, delivery and supply. Another goal must be a reasonable high level quality of energy and services. Also the use of local fuel resources can be one principle, but that must also be done in an optimal way with maximum efficiency.

Using optimal CHP production saves at least 30 % of fuel compared with separated heat and power production. If the separate production has not been optimised and facilities are old and inefficient, the saving might be more than 50 %.

System level design and optimization includes all parts and sub systems of municipal level energy systems. All planning and design is based on heat energy and electricity demand of the customers or other energy users. After that there are several possibilities to solve how the demand will be covered. One solution decision is to decide the production principles, which include for example the decision of used fuel or fuel mix. Also the role of CHP production must be decided. Main benefits will be achieved with the optimal use of CHP production.

After these steps it is possible to design sufficient networks and pipelines needed to deliver energy from production plants to end users. In district heating network design it is important to use the right principles in pipe design. Different types of pipelines need to calculate according their specific planning principles. For example main pipes from power plants and heating plants have different design border conditions than customer connection pipes. For pipe design and to operate network efficiently it is essential to make a sufficient number of hydraulic calculations of the network in different operation conditions.

Planning and design should be done so that it will support the operation and maintenance of district heating system. All equipment and systems should be coded ready to fulfil operation and maintenance system requirements. Most efficient is to use modern GIS based planning, operation and maintenance software systems.

2.1 Optimization of Energy Production

The essential step to achieve high efficiency of municipal energy system is to maximize the benefits of CHP production. It is important to avoid partial optimization of different energy systems and energy products, which often cause higher energy and fuel consumption than needed in optimal situation.

Optimal production must be based on the actual need of energy. In optimal energy consumption and in energy saving it is important that every customer can adjust the heat consumption individually to the needed level. All types of overheating should be avoided. Need of heat and electricity varies a lot during the different seasons of the year. In the following pictures typical heat loads and duration curves are presented.

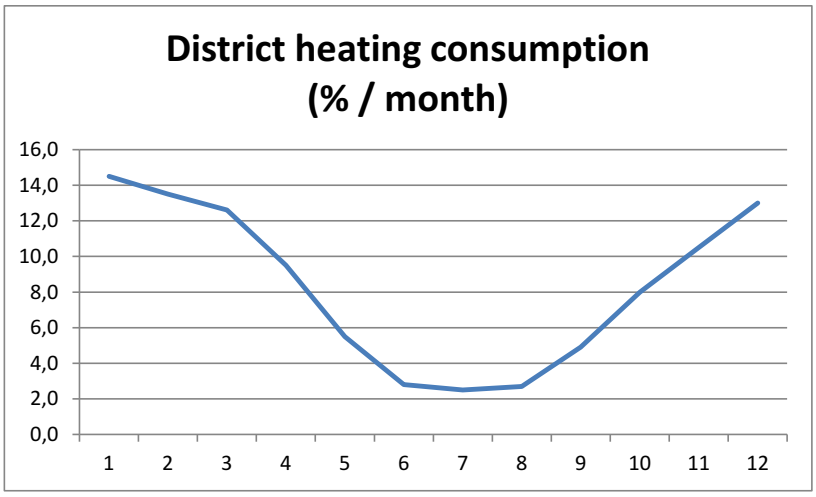


Figure 2: Typical consumption of district heating in Finland

In summer time only about 10 % of maximum heat capacity is needed. Heat is mainly used for domestic hot water production and for some other minor heating purposes for example in industry. This is the reason why there is need for more than one production unit in every district heating system.

A district heating duration curve of one Finnish town is presented in following picture. The lover curve represents calculated heating load i.e. without the capacity for domestic hot water.

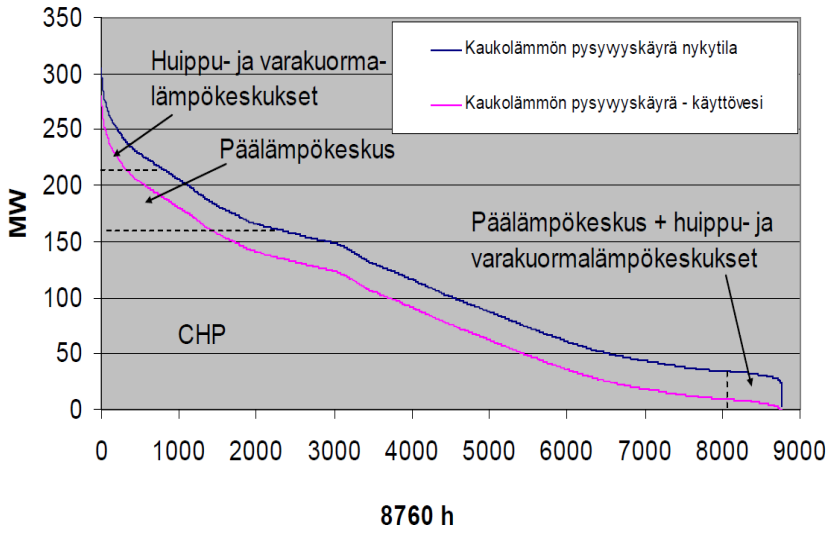


Figure 3: Duration curve of district heating (capacity / hours of year) [8]

The shape of district heating duration curve depends on the type and number f customers. Some bigger industrial customers may change the shape of duration curve dramatically. Space heating depends on outdoor temperature and building norms. Domestic hot water consumption is quite similar all year round.

The duration curve of total electricity consumption in Finland in 2008–2011 is presented in the following picture. It contains all electricity consumption including for example space heating and industrial use.

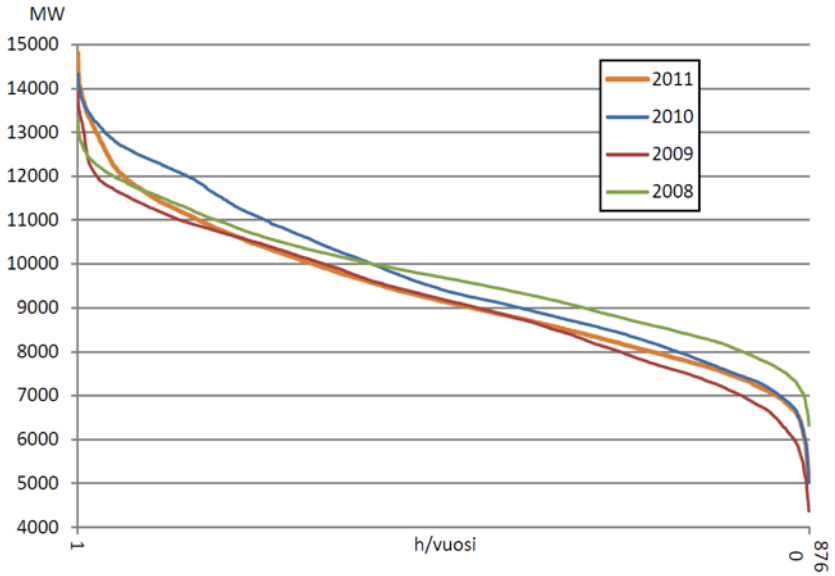


Figure 4: Duration curve of total electricity consumption in Finland in different year [7]

The general shapes of the duration curve of different years are quite similar. Changes are because of variation of outdoor temperature and because of different levels of industrial activity in different years.

The typical household electricity consumption in a one family house is presented in the following picture. It does not include energy for space heating or ventilation.

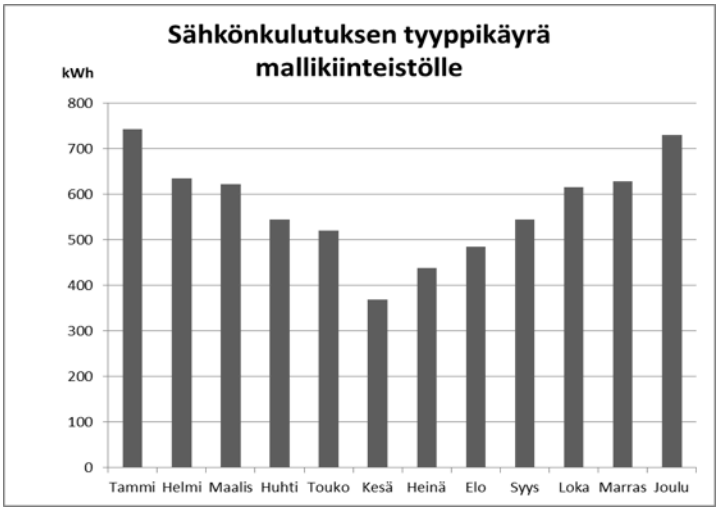


Figure 5: Typical electricity consumption of a district heated single family house [13]

One additional challenge in planning and design is that the duration curves of district heating and electricity are different. That means different design basis of basic load and peak load capacities and facilities for heat and electricity. However it is important to find an optimal solution to this municipal or regional optimization problem. The optimization criteria is to minimize the total fuel consumption i.e. primary energy consumption in the whole energy system.

Heating load is highest during cold winter period. Peak load of electricity consumption can also be during summer time because of increasing use of cooling energy. Also timing of industrial use is very important in electricity consumption and sometimes also in district heating demand. The duration curves and actual energy demand of industrial users can vary a lot in different seasons. Sometimes in some process the heat consumption can be constant throughout the year or even much higher in summer than in winter.

2.2 District Heating in Finland

District heating is an important heating and energy system in Finland. Almost 50 % of space heating in Finland is made by district heating. The market share of space heating in Finland in 2010 is presented in the following picture [18].

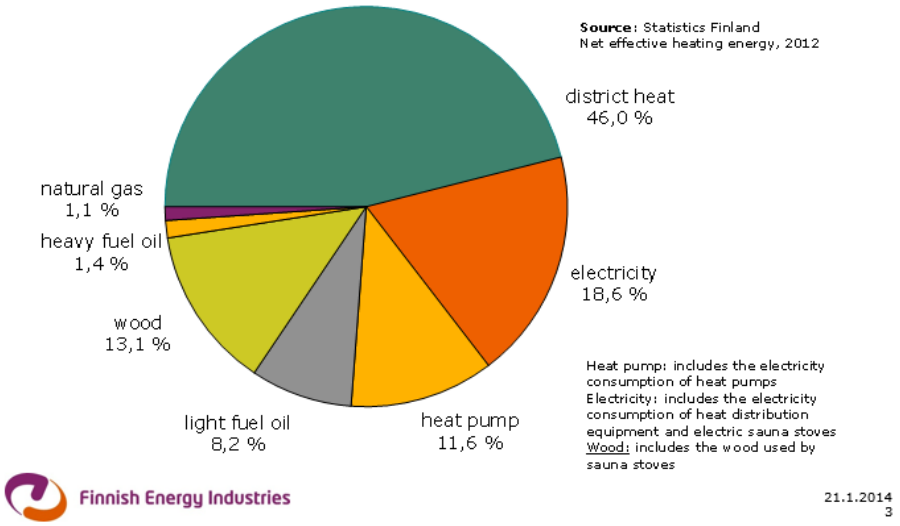


Figure 6: Market share of space heating year 2013 [18]

2.2.1 Heat production

The total district heat production in 2011was 34 030 GWh. About 72,5 % of the heat production came through steam or gas turbines or diesel units (CHP). The combined heat and power plants (CHP plants) produced electricity 14 490 GWh. In total, fuels were used 58 060 GWh in production of district heat and CHP production [17]. The fuels used in Finland for district heat and CHP production is presented in the following table.

Table 1: Distribution of fuels for district heat and combined heat and power production [17]

Fuel	2011	2010
Natural gas	31,4 %	35,1 %
Coal	23,3 %	21,6 %
Peat	17,6 %	17,8 %
Forest wood	11,8 %	9,3 %
Industrial wood residues	7,1 %	5,9 %
Other bio fuels	1,0 %	1,1 %
Mixed fuels	1,7 %	1,6 %
Industrial reaction heat	1,8 %	1,2 %
Heavy fuel oil	2,9 %	4,8 %
Light fuel oil	0,3 %	0,3 %
Others	1,1 %	1,3 %
Total	100,0%	100,0%

The development of co-generation (CHP production) in Finland from the year 1989 can be seen in the next picture. The share of CHO production increased already during 1970's and 1980's when district heating in largest cities in Finland was growing very fast. Suitable amount of heat load is an essential requirement for CHP production.

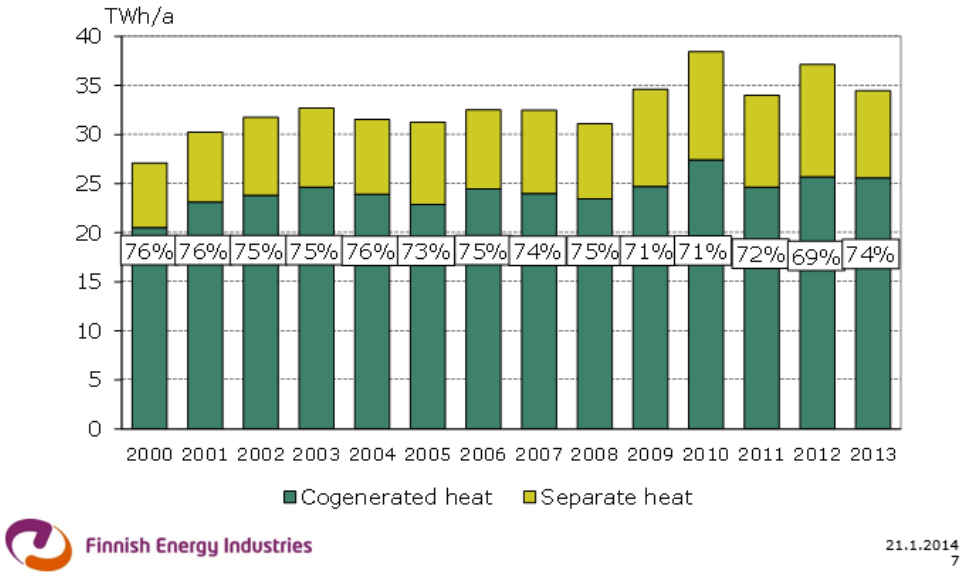


Figure 7: District heat production in Finland [18]

In Finland about 75 % of district heat is produced in combined heat and power production plants for several years. CHP production helps to decrease CO_2 emissions in energy sector. The calculated savings in carbon dioxide emissions due CHP in district heating is presented in the following picture [18].

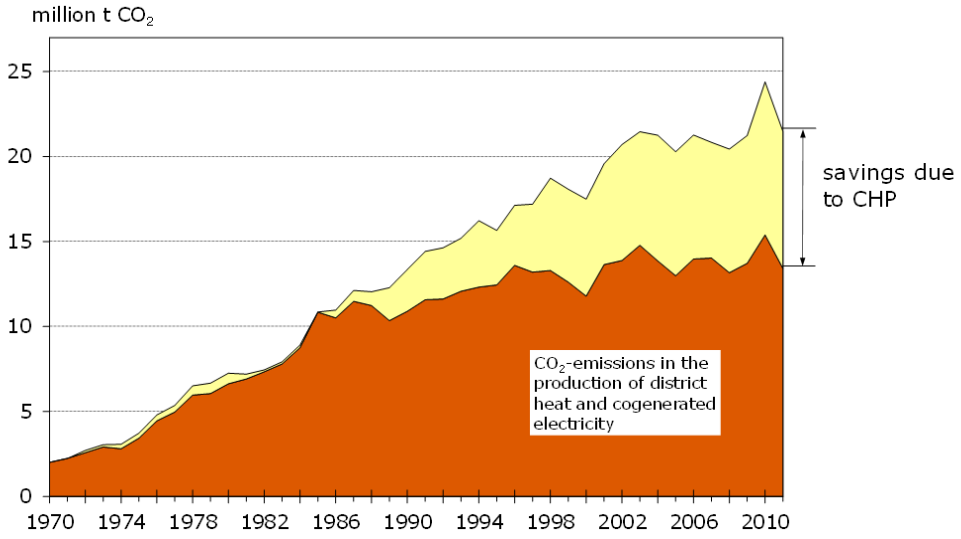


Figure 8: Savings in carbon dioxide emissions due CHP [18].

It can be seen that more than one third of emissions have been reduced because of CHP production of district heating. The development of production capacity and connected heat load of customers in Finland from the year 1970 is presented in the following picture.

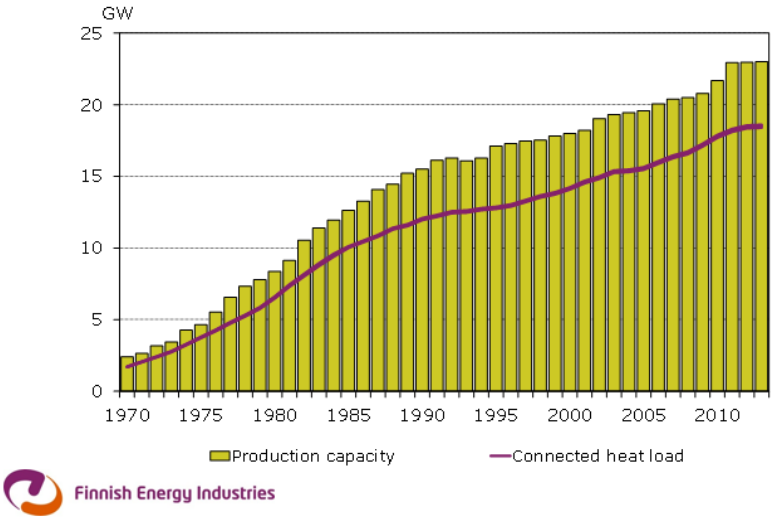


Figure 9: Development of production capacity and connected heat load of customers [17]

The growth of district heating was highest during the 1970s and 1980s. Most cities started district heating during 1960s and most of the existing apartment buildings, offices and other large buildings were connected in 1970s. At the end of 1980s only few old buildings were not connected into the district heating network. Later growth is mainly based on new construction of different types of buildings.

The growth of renewable energy sources used in district heating and CHP production in Finland is presented in following picture. Before 1960s wood was the main resource of heating energy in Finland. After that oil was so popular that the share of wood or other renewable energy sources was almost zero in district heating, which in fact just started in Finland in 1960s. That is why oil was the main fuel for some time. The first oil crisis in the beginning of 1070s started the change. First was natural gas available in South-East Finland and to Southern part of the country. Later renewable energy sources game more and more important.

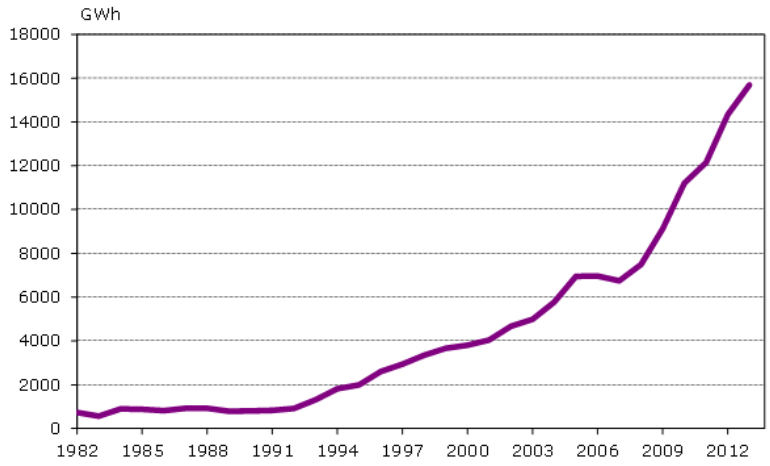


Figure 10: Renewable energy sources in the production of district heat and cogeneration [18]

In 2012 wood was about 14,2 % of fuels in district heating. Waste wood from industry covers about 7,4 % of fuels. Other biofuel were about 1,5 % of total amount of fuels. Waste heat from industry was 1,3% and peat 15,6% of the whole fuel demand in district heating. The amount of wood increased about 2,5 % units from the previous year and the use of peat decreased 2 % from 17,6 to 15,6 %.

2.2.2 Customers and consumption of DH

The number of customers in Finland was 133 500 in 2011. The connected heat load was 18 740 MW at the end of 2011. During the year 3 400 new customers were connected and the connected heat load increased by 290 MW, that is 1,6 %. The building volume of customers was 879 Mm³, of which the share of dwelling houses was 46 %. About 77 % of the connected building volume were new buildings while the rest were changing their means of space heating. 2,70 million people were living in district heated buildings at the end of the year. The heat delivery to customers was 31 200 GWh in 2011, which was 13,1 % less than in the previous year. The share of dwelling houses was 54 %, industrial plants consumed 10 % and other customers, e.g. offices and public buildings 36 %. [18] The heat sales with tariffs to customers in Finland during 2011 were 31 200 GWh (see the following figure). The arithmetical average heat sales price in 2011 was 70,5 €/MWh.[18]

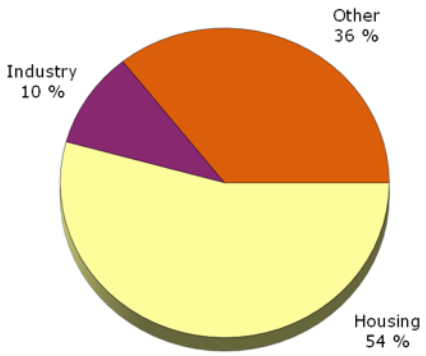


Figure 11: District heat consumption year 2011 (total amount 31,2 TWh) [18]

Most of the district heat is used by the housing sector, which is more than 50 % of the total consumption. Industrial use is only about 10 %. This is mainly because the largest industrial units have their own CHP plants and they produce their heat by themselves. Sometimes heat is delivered to a neighbor city or town.

The number of district heating customers and total length of DH networks is presented in following picture. It can be seen that the growth of pipes and number of customers goes hand in hand.

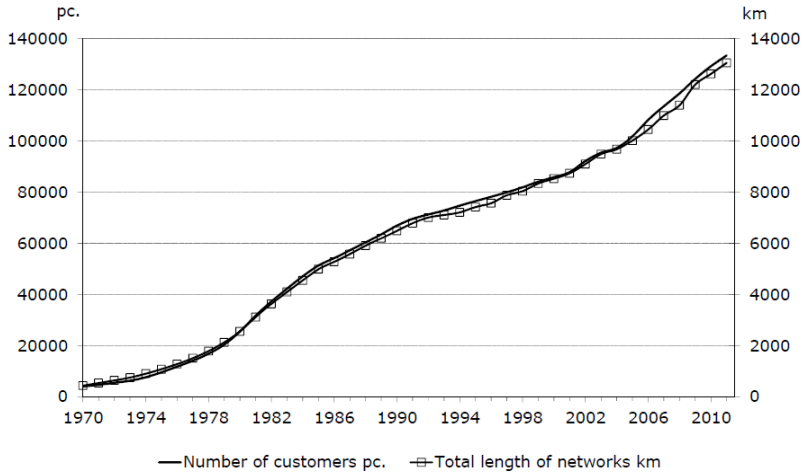


Figure 12: Number of customers and total length of DH networks [17]

From the picture it can be seen that during the mid-1990s and during recent years the number of customers has grown a bit faster than the pipe length. There are two possible reasons for that. Maybe there are more customers connected to existing pipes. The other reason might be that the share of smaller customers has increased. Even though the heat load per pipe length of smaller customers is lower the land area required for those buildings is also smaller and that why the need of pipes is also smaller. Of course the efficiency of district heating with smaller customers is a bit lower than that with bigger ones.

The specific heat consumption in district heated buildings was 38.1 kWh/m^3 in 2011. This heat consumption includes also the heating of domestic hot water. Specific heat consumption in district heated buildings in Finland is presented in following picture the.

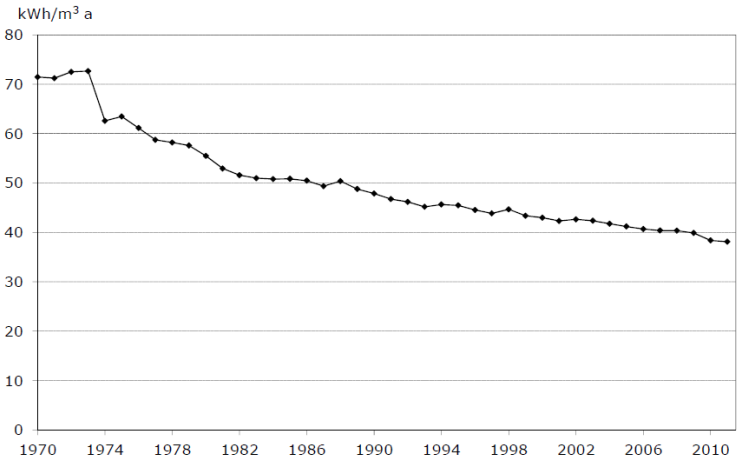


Figure 13: Specific heat consumption in district heated buildings [17]

The picture shows the decrease of energy consumption in Finnish buildings heated by district heating. The good development began in early 1970s after the so called first oil crisis. Also later energy crisis can be seen in figure. Especially in the beginning of the 70s the lower energy consumption was achieved by changes of customer behavior. These changes took place mainly because of information and motivation. Later development is mainly due to striker norms and recommendations of construction.

2.3 Experiences from Europe

In this chapter some experiences are presented in Europe regarding district heating and especially the use of renewable energy in district heating. The examples are from Great Britain, Germany and Austria. There are also several other countries where district heating and the use of renewable energy has increased during recent years.

2.3.1 Examples from Great Britain

District heating has not had a significant role in energy system and in energy policy in Great Britain. The situation has changed during few last decades because of increasing energy costs, higher environmental requirements and also because of EU level norms and directives.

The Community Energy Saving Programme (CESP) required energy suppliers and electricity generators to deliver energy saving measures to domestic consumers in the most deprived areas of Great Britain. In the Community Energy Saving Programmes final report district heating reduced 1.6 million tonnes of carbon and benefited more than 24,000 households in the UK. This shows that district heating is a viable way to save carbon and consumers' cash, and the UK looks forward to similar results from the new government obligation on energy suppliers." [16]

One example of development of district heating and bio energy is the Hoathly Hill district heating project in Great Britain. Hoathly Hill Community lies on the outskirts of West Hoathly village in the rural landscape of the High Weald AONB. The Community was established in 1972. There are 27 units, ranging from single person flats to 4-bedroom detached family houses inhabited by around 65 people The aim of the Community is to work together to provide a supportive and sustainable cultural, social and physical environment for everyone who lives there and to reach out to the surrounding environment to share what we learn from this experience. [26]

Reasons to this biomass heating project were climate change, carbon neutral ambitions, renewable energy, use of local natural resources, landscape protection, environmental responsibilities, cost saving. The main part of the project was a modern, low maintenance wood chip boiler system. The project cost was nearly £400k. [26]

The old heating situation consisted of an LPG network piped to 75 % of the houses with associated gas boilers, ranging from efficient combi-boilers to older and less efficient standard gas boilers. For other homes, a mixture of electric storage heaters and wood stoves, plus electric immersion heaters were used.

The annual heat load for the site is calculated at just over 750, MWh, with a maximum heat load demand of 300–350 kW. This figure has been derived from standard heat calculations for the type and age of buildings, as well as checking these against the LPG, electric and wood heating bills. Total annual costs were estimated at around £30,000, including repair and maintenance. The annual cost for the wood fuel is estimated at around £14,500 a year, including all costs like administration and overheads. [26]

Figure 14: Wood chip boiler in Hoathly Hill district heating system [26]

The district heating system consists of 300 kW wood chip boiler and insulated flow and return pipes to all the houses. Pipes were connected via an interface unit to the internal heating and water heating system. Two 4,000 litre buffer storage tanks (stratified accumulator tanks) were designed to deliver peak output whilst the boiler is sized at about 70 % of the peak load i.e. about 420 kW in this case. [26]

Wood chip to fuel the boiler is produced at the Balcombe Sawmill. The quality of wood chips will be provided at 30 % moisture content. The woodchip must meet the G30 and W30 quality specification required by the boiler. Excess slab wood from the mill is chipped to produce a high quality chip, of uniform G30 size with low moisture content. What was previously wood waste is now converted into a valuable product with consistent demand. The boiler will require approximately three hundred tons of wood chips annually. [26]

Pre-insulated pipework for circulating the hot water to each building has been designed to be a low heat loss type, which means less than 0.01 °C per 100 meters. The insulation is bonded to the plastic pipe ensuring that no external water can be in contact with the pipe, leading to significant heat losses. There is approximately 1.4 km of pipework connecting the boiler to the interface units. [26]

Figure 15: Flow and return pipe joints of district heating pipeline in Hoathly Hill district heating system [26]

In the picture it can be seen that there might be a significant risk of failures and future corrosion because of outside water in customer connection pipes.

CO2 savings

The potential CO_2 savings will depend on the type of fuel to be used and that being replaced. Statistics from the UK indicate that the amount of CO_2 released per kWh of heating oil is approximately 0.26 kg/kWh. The emissions for natural gas are 0.19 kg/kWh. The net CO_2 emissions from wood fuel is officially close to zero, except for emissions in producing and transporting the fuel, any emissions in manufacturing and installation and the electricity used in running the pumps, fans and control mechanisms.

Using a local fuel (wood chips) produced within 5 to 15 km of the site and delivered this short distance should lead to relatively lower transport fuel emissions than that for LPG, which has been transported long distance by sea and road. LPG has the advantage of being a more dense fuel than wood chips, hence requiring less delivery trips throughout the year.

2.3.2 Example from Germany

Germany has a total population of 81.8 million inhabitants, of which 14 % are served by District Heating [23]. This is much lower than in Nordic countries or in Eastern Europe but higher than in Western Europe in average. In Finland the share of district heating is almost 50 % (see chapter 2.2.).

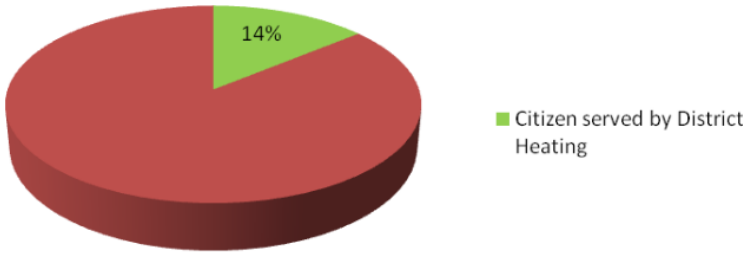


Figure 16: Share of District Heating in Germany [23]

In Germany the City of Munich is one example of reducing CO2 emissions by using district heating. Munich aims to cut CO_2 emissions in half with district heating powered by renewable sources.

Stadtwerke München, the utility company in Munich, Germany, aims to supply every customer with renewable energy by 2025, reduce CO_2 emissions by 50% by 2030 and become the first German city to have district heating that relies solely on renewable sources by 2040 [11]. Munich is one of the few cities in the world that has taken global warming by the horns. One of Munich's new environmental goals is to become the first large German city with a district heating system powered completely by renewable energy [11].

Stadtwerke München, has started an expansion program with an investment volume of € 200 million in order to supply a further 140,000 apartments in München with environment-friendly energy [22] . At the same time the goal is to save 300,000 tons of CO_2 that would have been generated by conventional heating methods [11].

To implement this ambitious vision, Stadtwerke München will be concentrating on further tapping of geothermal energy over the next decades. Once this renewable energy source is being utilized to the full, there is the possibility in a final step – depending on technical developments and availability – to fall back on the two "green fuels" of biogas and wind. The renewable (biogenic) proportion of residual waste could also play a role. [22]

Thanks to energy savings and energy efficiency measures such as optimizing buildings, the vision has the advantage that the amount of energy required for heating purposes will decrease step by step over the long run, whereas that for hot water will remain fairly constant. In other words, deployable geothermal energy will cover an increasing share of total demand over the coming decades. Thanks to their favorable location in the Bavarian Molasse basin, München and its southern peripheries are in a privileged position regarding exploitation of hydrothermal geothermal, benefiting from a circumstance that applies to few other German regions: a huge store of environmentally-friendly energy in the form of a hot water deposit with temperatures ranging from 80° to 140° centigrade some 2,000 to 3,000 meters below the earth. This hydrothermal water is ideal for use in heating, and at particularly high temperatures also for power generation. [22]

Munich also boasts one of the largest and most effective district heating systems in Europe. The network uses over 800 km of insulated pipes to distribute environmentally friendly heat throughout the city, powered by 4 billion kWh of annual waste energy from Munich's power plants. It is a highly efficient system; to put it in perspective, generating the same amount of heat energy using oil-powered household heating systems would require 450 million litres of heating oil, which would release approximately 1.1 million tons of CO2 into the air. This is equivalent to the amount generated by all of Munich's automobile traffic in a year. [11]

2.3.3 Example from Austria

Austria has developed district heating and use of renewable energy sources during the recent years. The production of district heating in Austria in the years 2005–2009 is presented in following picture

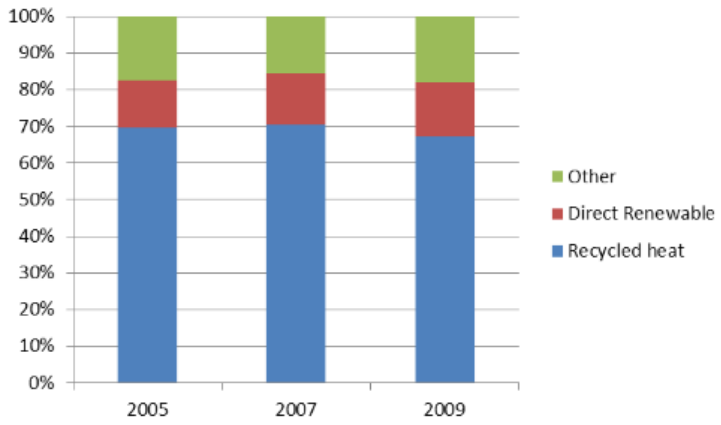


Figure 17: Production of district heat in Austria [19]

Several villages in Southern Austria are supplied with district heating based on Biomass. Biomass is a buzz word in the hilly countryside around the village of Wiesmath in Lower Austria. Several villages in the area are being supplied by district heating from local biomass-fuelled heating plants. [20]

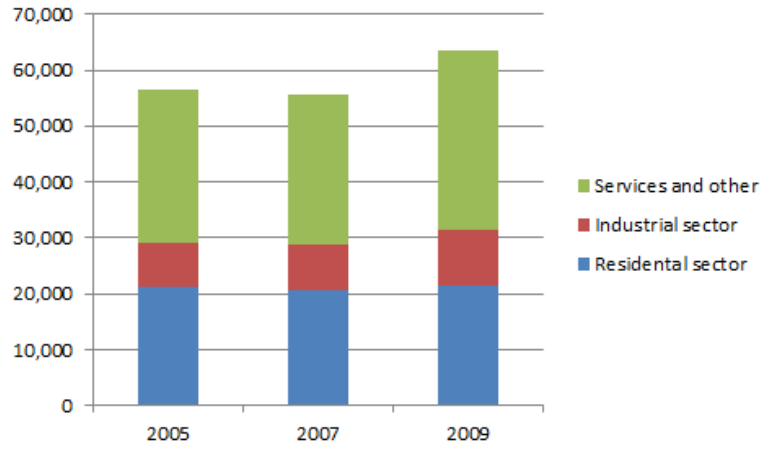


Figure 18: DH customers in Austria [19]

Share of residential customers is much lower then for example in Finland. Services and other customers is the major costomer group in Austria.

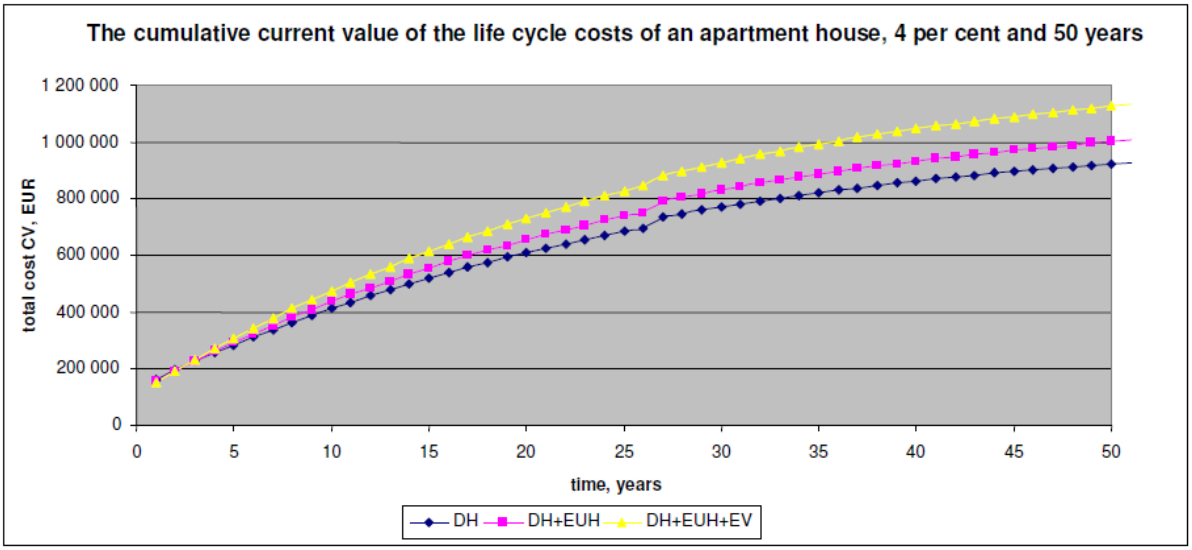
Austrian City of Graz has installed already in 2009 a large-scale solar thermal plant. The plant includes 3,980 m^2 of collector area, which are set up in an area that the water supply company Graz AG uses for water runoff. Installations began in March 2009 and were completed in May. The generated heat is fed into the Graz AG building on site, as well as into the district heating system of the city of Graz. The so-called HT collectors have been specifically developed to produce high temperatures (over 85 °C) and achieve better performance results than most vacuum tube collectors would on clear days. The new solar thermal installation is the latest of a series of several large-scale solar thermal plants in and around the city of Graz. The Graz District Heating has now installed a total of 6.5 MW of solar thermal capacity to help meet a demand of 14 MW during the summer months. [21]

2.4 Risks of decreasing efficiency in Finland

In Finland so called hybrid heating systems in buildings heated with district heating have increased dramatically during the last 15 years. Mainly it is a question of electricity heating in some parts of the heating system in buildings. According to Mäkelä etc. “Additional Heating Sources in District Heated Buildings and the Environmental and Cost Effects on the Community” [5]. “In the district heated buildings constructed in recent years in Finland electricity has become a heat source for under floor heating of wet spaces and for heating the incoming air. According to this research the use of electric heating in district heated buildings is unprofitable considering the life cycle costs. In certain cases the investments are a little more expensive if the building is entirely based on hot-water central-heating system” [5].

This miss understanding of lower investment costs is the main reason to use electricity together with district heating. People also have the image of easy feasibility of electric heating and affordability of the investments. Minor reason might be that people are afraid of the risk of leaks in district heated under floor heating.

In the research of additional heating in DH heated buildings [5] it was found that additional heating systems are not profitable in district heated buildings. In the case of row houses and apartment buildings, the comparison included mere district heating and district heating combined with two different electrical alternatives, electrical under floor heating and electrical heating of the ventilation. These three cases and their investment and life cycle costs were compared during the life cycle of 50 years.



EUH = Electric under floor heating
EV = Electric heating in ventilation

Figure 19. The cumulative current values of the life cycle costs of the heating systems of an apartment building [5]

The life cycle costs of hybrid heating in an apartment building (7000 cubic meters) increase over 200 000 € if both electrical heating systems are used. During the life cycle the mere district heating solution is about 80 000 € cheaper than district heating with some electrical under floor heating systems.

In the picture it can be seen that in year 25 the district heating substation will be renovated. It make any important impact on the cumulative lifetime costs of an apartment building. Most important parts are the energy costs.

Installation of electricity heating system is often a bit faster than installation of water based heating. Construction companies find it important to finish the building process as quickly as possible, while the future user would prefer the minimization of the annual costs and overall lifetime costs. The use of electric heating in district heated buildings decreases the possibilities for the utilization of environmentally-friendly CHP production. As the need of district heat decreases, the same time the need of electricity increases. Both the electricity lost by this decrease of district heat load and the additional need of electricity must be covered some other way. The hybrid solutions of district heating and electric heating are a threat to efficient cogeneration of district heat and electricity. The use of electric heating as a parallel form of heating together with district heating causes a remarkable addition to the costs and the emissions of energy production of the community. The residential costs are most affordable during the life cycle when no other energy source is used for heating in addition to district heating.

Regional level impacts in fuel consumption

The use of electricity instead of district heating increases the regional or municipal level fuel consumption. When decreasing CHP production also the amount of electric energy generated by the combined production decreased. This share of electric energy lost by decreasing cogeneration and additionally the share of the increase of the use of electric energy were needed to be produced separately.

The alternatives of energy production in the research project were natural gas or biofuel as the primary fuel. In the first alternative, natural gas was used as the primary fuel of energy production. Natural gas is used also as the fuel of the main district heating plant.

The reserve and peak load heating plants work with heavy fuel oil. In the second alternative biofuels (milled peat and wood) were used as the primary fuel. The CHP plant and the main heating plant used a mixture of peat and wood in the proportion of 50-50. The reserve and peak load heating plants worked with heavy fuel oil. The energy production alternatives included also a possibility for separate electricity production by coal condensate power.

The increase of carbon dioxide emissions in a city of 100.000 inhabitants was from about 50 000 to 2 500 000 tCO_2/year depending on fuel used for CHP and electricity production. The increase in the costs was from 500 000 €/year to over 5 000 000 €/year [5].

3 Heat Production

The main basis for an efficient regional or municipal energy system and district heating production is optimal use of cogeneration of heat and electricity (CHP production). The use of several heating plants, both CHP and heat only boiler, in the same district heating network is an essential requirement for optimal operation of heat generating units and maximizing CHP production and overall efficiency of regional level energy system.

One advantage of district heating with several production units is the possibility of using different types of fuels. This is a possibility to achieve minimum fuel costs with minimum environmental stress. CHP production needs optimization. It is not enough to have a CHP plant as there is also a need for peak production units for optimization of heat and electricity production.

In Russia, the optimisation calculations have not been based on the total optimisation of energy production in a town or city, perhaps mainly because there has not been a lack of fuel. Also, the extremely low price of fuel caused misunderstandings in the economical calculations. In Russia the principle has been that the heat load must be at least 300–500 MW before CHP has been installed. That's why a lot of sufficient heat load has been missed. There is enormous amount of capacity to increase the efficiency in energy sector with CHP production. Another mistake is to separate different networks in the city or village. This makes it impossible to optimize peak production and low demand production of heat and lower the total efficiency in municipal level at least 30 %.

To achieve the maximum benefit of district heating, the production plants should be used as efficiently as possible for optimizing the efficiency of heat and electricity production and minimizing the use of fuel and pumping energy.

3.1 Development of District Heating and CHP Production in Russia

The following picture illustrates a typical district heating solution of a Russian city, where the heat production of different city areas is carried out by independent boiler plants or CHP power plants in separate district heating networks.

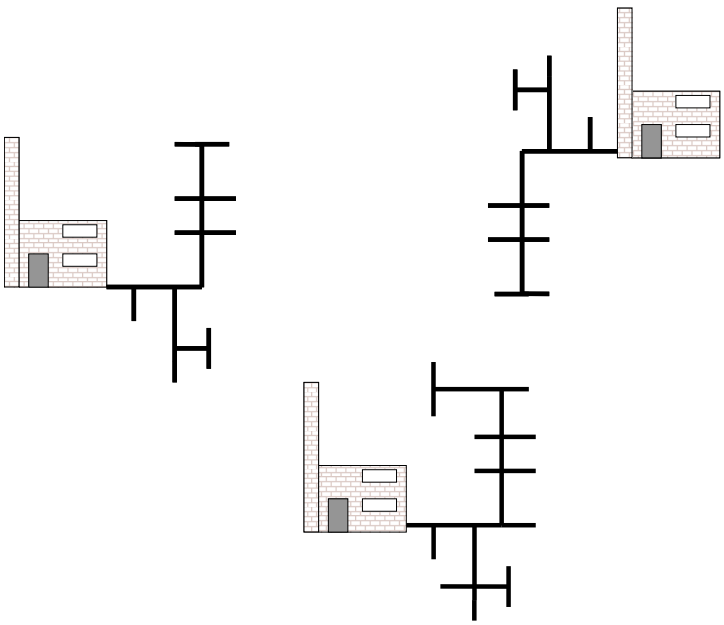
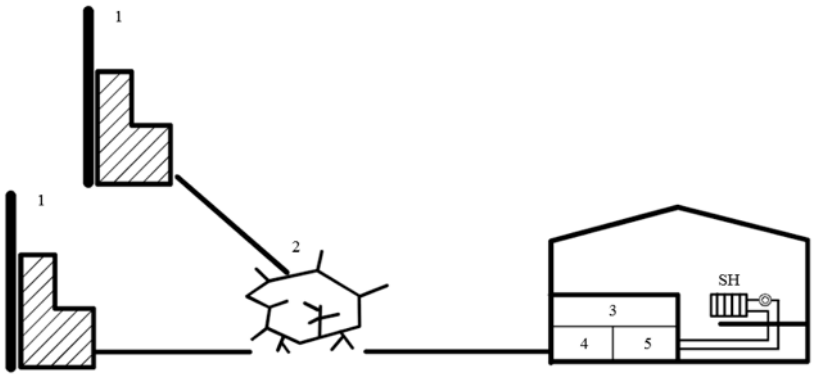


Figure 20: The Russian district heating system, separate district heating networks and heat production units

In this kind of solution, the co-operation of the different power plants or other production units cannot be exploited optimally. The best efficiencies of the power plants and boiler plants cannot be achieved. This is because it is impossible to operate separate production units in optimal operation load and with maximum efficiency. This is because none types of the energy production plant types can operate with high efficiency with partial production load. The best efficiency can be achieved close to 100 % capacity of the plant. It must be remembered that district heating load varies from 100 % in winter to about 10 % in summertime in Finland. The variation is quite similar in same type of climate conditions, especially when the building norms are close to each other.

In the Finnish district heating system, the network in a city or town level is built together and often in loops. Different production plants are used appropriately according the optimization of the efficiency of heat and power production.



1 CHP plant or boiler plant
2 Network
3 Customer connection
4 Metering equipment
5 Sub station

Figure 21: The principle of the Finnish district heating system

Heating plants are either CHP plants or heat only boilers. In every town there is at least one CHP plant for heat and electricity production. Different production units can be operated in optimal way. The main goal is to minimize the fuel consumption and maximize the overall efficiency of the system.

There are possibilities to improve Russian district heating system to achieve impressive improvements in regional level energy efficiency. While planning the rebuilding or other development of the Russian district heating systems, it should always be considered, if there is a possibility to simultaneously combine the separate plants as a part of a uniform district heating network. This is illustrated in the following picture as a development of the network presented in previous figure of Russian district heating system with separate networks.

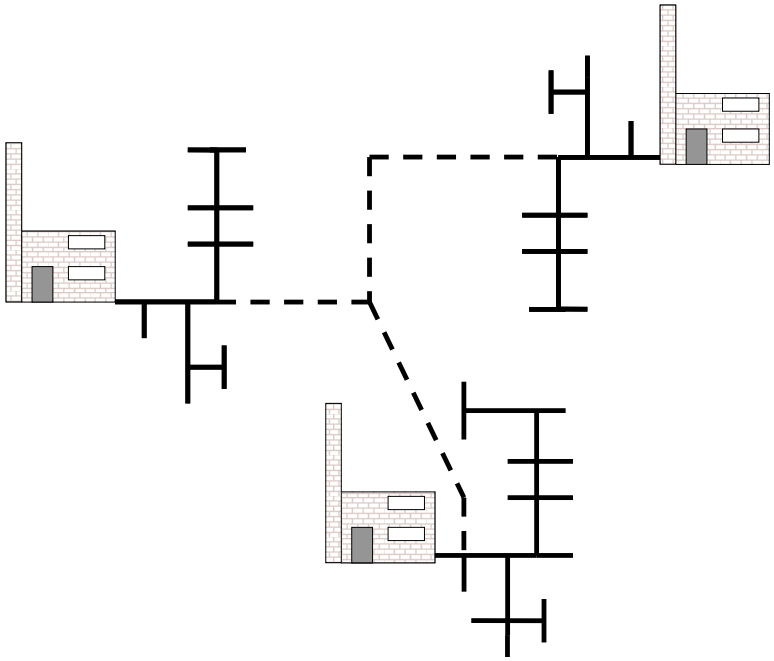


Figure 22: Combining of separate networks, including CHP in at least one production plant.

In this situation, not only do both the condition of the boiler plants and pumping devices and the sufficiency of production capacity have to be assured, but the sufficient capacity of the network segments planned to be used for the combination (as dash lines in the picture) also has to be assured. The junction cannot always be made to the nearest pipe, because it has to be large enough for transferring the needed amount of heat. Quite often the direction of heat delivery changes depending on the system's balance. However, this does not cause any harm to the customers or to the DH network.

This kind of connection, which originally consists of separate networks, requires that the district heating system is based on a customer-specific control system operating in building level. In that case, the automation and integrated use of different boiler plants is easy to implement by quite a simple automation system or even manually from manned boiler plants.

3.2 Heat Production Control and Planning Philosophy

The basic planning philosophy of the Russian DH system is that everything is controlled from the top to the bottom i.e. from heat production plant to customer. That is why there is no accurate customer level automation, which allows every customer to independently make adjustments and control their energy consumption. A complex hydraulic system is not easy to balance and operate from one point and that is why there are many small DH systems in Russia lacking the overall optimization of the municipal or regional level CHP production.

In Finland the whole system is planned to serve the need of the customer. The total need of heat production is always the sum of the individual needs of all customers. This gives better control and energy efficiency in the consumption level, but all the equipment and systems must be planned to fulfill this need. In Finland every customer has a building level substation with sufficient automation system.

Planning basics of district heating system:

- Maximum CHP heat and electricity production with maximum efficiency
- Energy efficient planning and design both in building and production level
- District heating delivery system optimized but also flexible enough to serve all customers
- Heat production controlled according to customer needs
    - Sufficient supply temperature
    - Enough pumping i.e. pressure difference in DH network
    - Enough production capacity
    - Reserve capacity optimized
- Minimum burden to environment

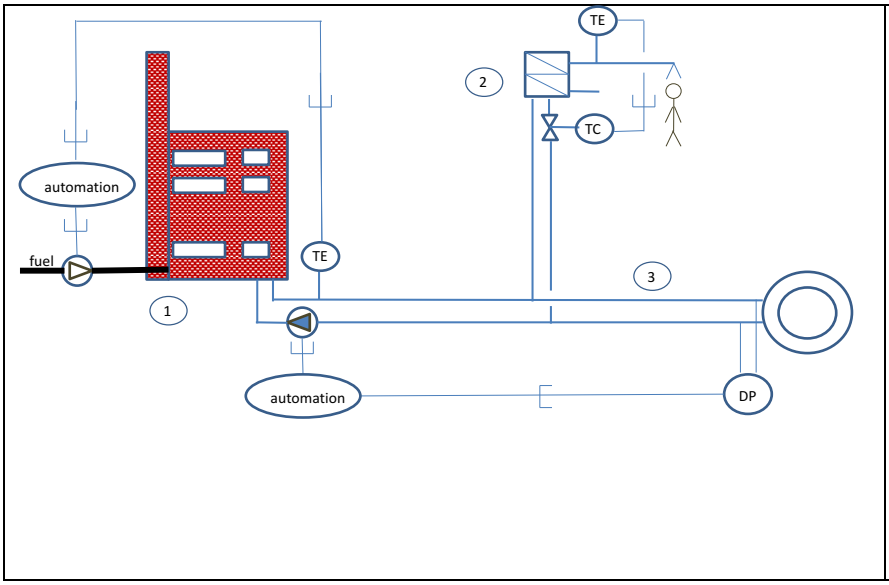
Automation Principle of DH system

Main automation processes in district heating system are as followings

- Setting the district heating flow temperature from each heating plant. Set value must be the same in each boiler plant and in CHP plants.

- Adjusting the pressure difference between the district heating flow and return pipes. This requires pressure difference measurements from different points of the district heating network. In theory the control signal needs to come from the most difficult customer i.e. from customer where the pressure difference is the lowest. The measurement can be also in some other point of the network, but the knowledge of the behavior of the network must be clear.

Basically a district heating system is automatized as shown in the following picture.



Where:

1 = CHP plant

2 = Customer

3 = District heating network and other customers

4 = Other boiler plant or CHP plant (next picture)

Figure 23: Automation of a DH system

District heating flow temperature is adjusted with fuel control. Increasing fuel input the temperature gets higher. Pressure difference is adjusted with pumps. Increasing the speed of the pump will increase the pressure difference. In the example presented in the picture the only adjustment in district heating system is a customer who needs hot water in shower.

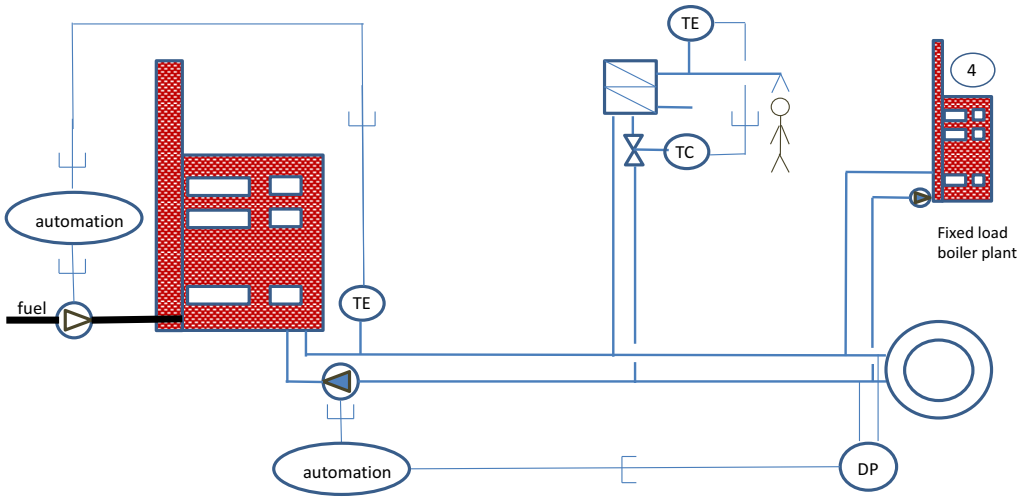


Figure 24: Automation of a DH system with more than one production units

Principles of using additional heat production units (boiler plants or CHP plants) in the district heating system are as following:

- In every production plant the district heating supply temperature setting is equal
- One plant takes care of the pressure of the network (one pressurising system is in operation)
- Only one plant controls heating capacity and pumping (any of the plants can be controlling unit)
- All other plants are on fixed load (heat load and pumping)

This means that the system is once again one production unit system, and all the other plants are only fixed load negative customers from the viewpoint of controlling and automation.

Quite often heating and domestic hot water are produced in separate boilers in boiler plant. Separate production requires separate pipelines to customer.

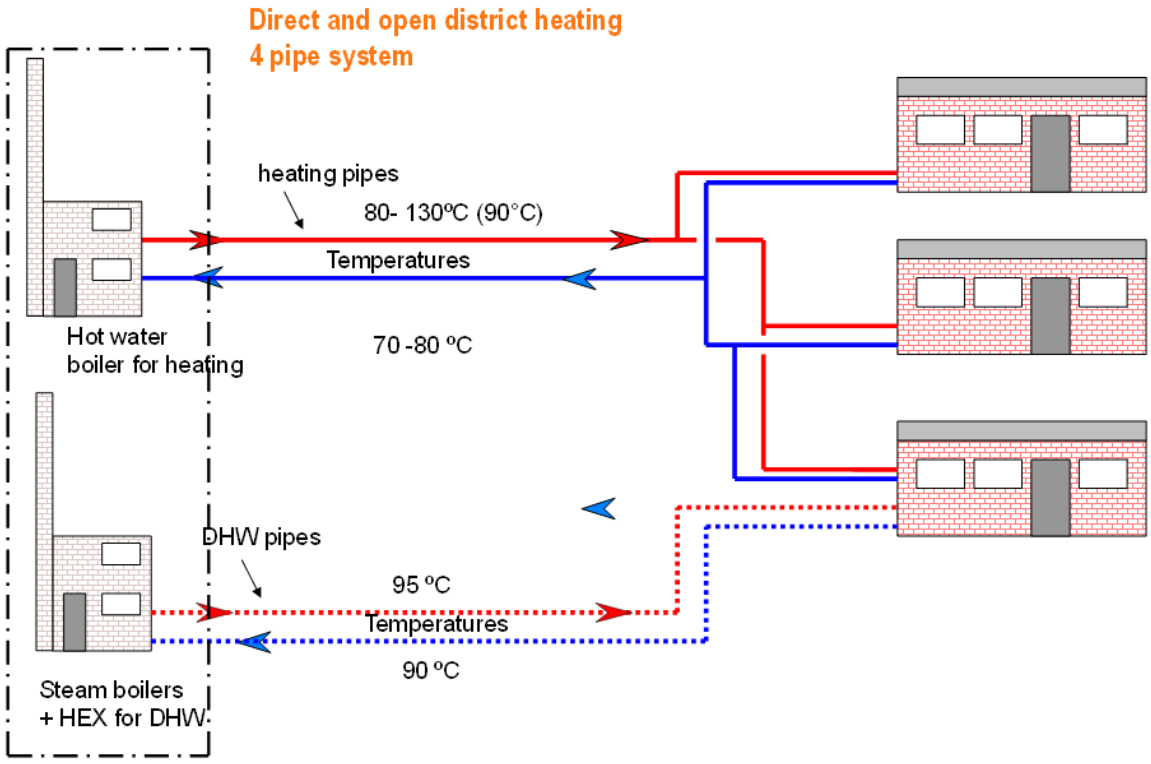


Figure 25: Direct and open district heating system (4 pipe system)

4 District Heating Network

4.1 Planning and design of district heating network

In planning and design of district heating network the main tasks are sizing the pipes, hydraulic calculations and analysis of pressure losses in pipes and calculation of heat losses from network. Different networks and different types of pipes must be designed and sized according to local conditions and other related information. The actual location in district heating network has influence on design values. Main data will be existing pressure difference and available pressure loss of the pipe and actual temperature difference of planned pipeline and of course the needed heat delivery capacity of the network. It is important to analyse and calculate the pressure losses not only with design values but also in other operation conditions. The situation varies a lot for example in summer to compare with winter conditions. Network calculations make it possible to optimise different conditions: production facilities, pumping devices and other operation activities.

The general planning values of district heating network in Finland are as following. The design temperature of flow pipe is 120 °C and design pressure of district heating pipes is 1,6 MPa. The water treatment should be done according Finnish district heating recommendations.

4.1.1 General design of district heating network

Planning and design of district heating network should be based on heat demand of district heating customers and prognosis of future customers and their heat demand. The need of existing buildings should be based on measured heat or fuel consumption.

New buildings can be based on design data of heating, ventilation and domestic hot water consumption and other possible heat demands like industrial processes. Future city areas and new regions must be based on predicted data, which must be based on city planning information from communal planning board. Another boundary condition is the location of heating plants and power plants. Also future plans for heat production must be considered in network planning. A good planning span of general network plan is from 10 to 15 years [36].

District heating network planning is also a plan for future development. One task is to decide and optimize when to construct different pipelines. The plans and information from communal planning board is a very important tool for this planning. It is also possible to begin with a smaller pipeline, which can be renovated when the heat demand has increase enough. Investments in network are huge, that is why it is important to optimize the use of resources. The main work is the economic and financial optimization of investments so that considerable high level energy services are secured.

Other cables and pipelines must be considered in network planning and design. Also other buildings and other constructions must be taken care of both in planning and installation.

4.1.2 Sizing of pipes

Pipes should be planned to about 10 to 15 years' view of heat demand of existing and new customer. The lifetime of pipes should be planned at least for 30–40 years. Sometimes it is not necessary to build the final size of network at the beginning. Sometimes an additional pipe can be constructed later or a booster pumping station can be the solution of increased pressure losses.

Main design values are the needed heat transfer capacity and allowed pressure loss in the pipe (bar/km) and the temperature difference between flow and return pipe. To calculate the pressure loss and to design the correct pipe size the pressure difference in

the beginning of the pipe has to be known. Design values must be known during the most difficult operation condition. Also the location of the pipe in the whole network structure has an influence on the design.

All pipes should be designed according the real need of the heat in different consumption places. The pipe diameter will be calculated according needed heat capacity, actual temperature difference and allowed pressure loss in different pipes. The design values can vary from maximum heat load and temperature difference in winter to situation in summer time when only domestic hot water is demanded but when the temperature difference is much lower.

4.1.3 Main pipes from heating plants

Heat load is the total capacity of the heating plant or CHP plant. Sometimes the capacity value can be the total heat load of the district heating system i.e. total sum of the heat demand of customer. The demand of domestic hot water can be ignored i.e. the contemporary factor is zero.

Temperature difference between flow and return pipes in calculations is about 30°C [36]. This value differs quite a lot from the design values of district heating customer.

The allowed pressure loss of pipes are in normal planning situation 2 bar/km network (i.e. 1 bar/km, pipe), sometimes 1 bar/km network (i.e. 0.5 bar/km, pipe)

4.1.4 Design of main delivery pipes

Main pipes are planned according the total heat load of the region or city area. Because the demand time of domestic hot water use varies in different building the contemporary factor is used. The value of the factor is about 0,7 (sometimes to 1.0).

Temperature difference between flow and return pipes in calculations is from 40 to 50 °C [36].

Normal 2 bar/km network (i.e. 1 bar/km, pipe), sometimes 4 bar/km network (i.e. 2 bar/km, pipe).

4.1.5 Design of customer connection pipes

Connection pipes will be calculated according the actual heat load of existing customer or according to short scale and sure future construction plans. This is different from the 15 years principle of main pipes and other large pipeline.

Quite often the design of customer connection pipe must be done according the summer situation. It must always be calculated both in winter and in summer situation to achieve the correct pipe diameter. The heat demand is a combination of domestic hot water, heating and ventilation heat loads.

Temperature difference in customer connection pipes is normally from 50 to 70 °C. In some special cases, for example when there are some processes to be heated, it can be lower. The pressure loss of network is 4 bar/km (i.e. 2 bar/km / pipe), at the end of the network 2 bar/km network [36].

4.1.6 Hydraulic calculations of district heating network

It is essential to know how the district heating network acts. Most important is to know the actual pressure losses of different pipes. The situation in pipes and the location of most difficult point of the network may vary during different seasons of the year. Also new customers may affect with unexpected changes to the behaviour of the district heating network.

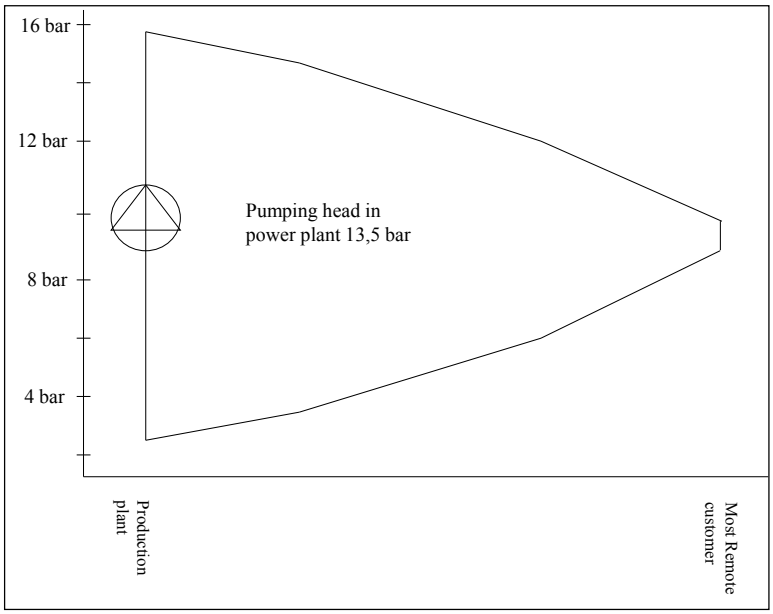


Figure 26: Example of an illustrative drawing from a hydraulic calculation of the district heating network.

The calculated pressure of the district heating network from production plant to some point of the network is presented in the figure. In this case the end point is the most remote point of the network. Often we are interested in the situation of the most difficult customer. According Finnish district heating norms the minimum pressure difference in customer level is 60 kPa. It is the minimum pressure difference to ensure the functionality of customer substation equipment. It is important to make several simulation of the network to find out how to operate and how to improve the network.

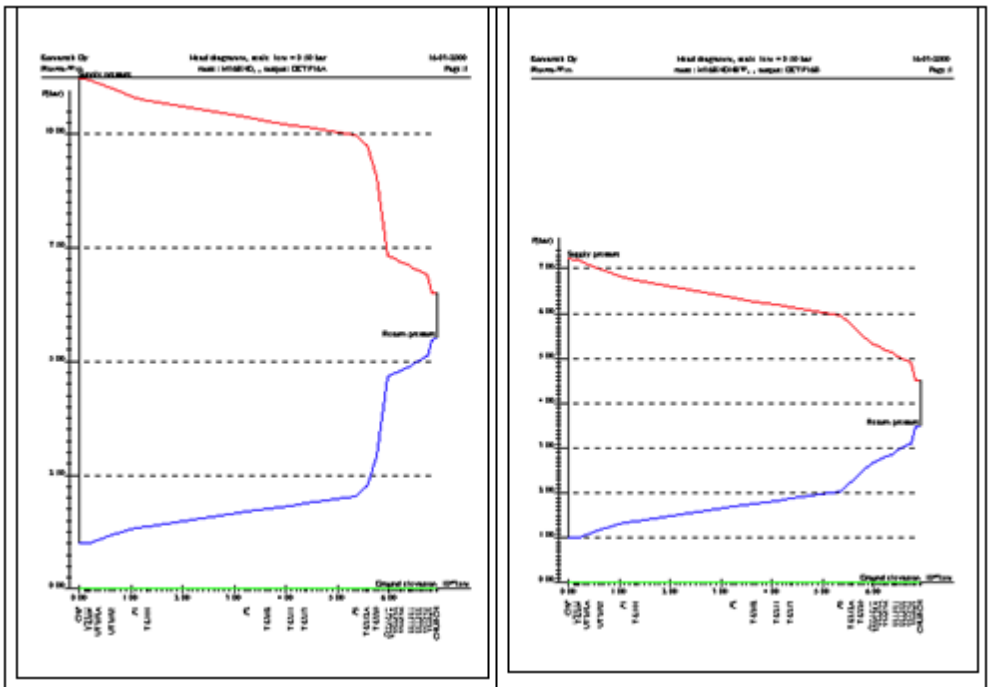


Figure 27: Example of district heating network hydraulic calculations.

The picture shows in left present situation and right pressure difference with renovated short pipeline, which has become too small because of the increased number of customers in the city region behind that pipe. The length of too small pipe was only about 400 meters.

4.2 Operation and Maintenance and Service Actions in DH Network

In Russian and Finnish cultures operation and maintenance and service actions have different content. In Finland operation and maintenance is part of everyday action to keep the system in good condition. In Russia the maintenance is mainly carried out during the summer break. In Russia according the national regulation there is always a summer break for maintenance and service actions. Quite often it is a very long period without any heat delivery to customers. According the norm district heating network must be emptied for the service period.

In Finland all maintenance and service actions are made during normal operation because there is very little need for O&M actions in DH network. The main principle of the operation strategy is to sell heat all year round. Reasons for very short cut of times are for example: high level quality system in district heating network, sufficient amount of loops in network, peak boiler plants are located in different parts of the DH network (different regions of the city or town), good planning and preparation of the repair work. There is no frequent need of service breaks in Finland. The actual break is planned to be as short as possible.

In Russia the regulation of the Constructional and Residential Municipal Economy Commission of the Russian Federation "The regulations and norms for using residences" states what must be done to the district heating system in summer. These regulations seem reasonable in theory, but in practice they are more harmful than helpful to the quality of district heating system and district heating services.

- Heating season is limited because the norm requires a service period for DH system
- By the end of heating season network flow tests are arranged to indicate the most damaged parts of the pipeline
- O&M period can be several months during the summertime
- Whole district heating network (whole district heating system) is emptied for service
- By the end of repair and service works the whole system is filled by water. Pipeline and equipment tests are arranged.

This mode of operation caused by the norm creates several problems, for example:

- Heat delivery is limited because the service period lasts several months
    - Less income to district heating company
    - Lower heat quality for customers
        - Customers are eager to have their own heating facilities and in worst cases, want to disconnect from the DH network

- Emptying the pipes greatly increases the corrosion of district heating steel pipes. Corrosion causes fast damage to the pipes. It also increases the amount of particles (magnetic material) in the DH water, as well as the necessity of additional costs for water treatment and its heating.

- Mechanical stress in pipes increases because of annual flow tests and cooling of the pipes to ground temperature each year. It seems that these factors together with the increasing corrosion rate seriously influence shortening the actual life span of district heating networks.

In Finland the planning and implementation of the district heating system aims at a year-round system with minimum breaks in the heat supply (disturbances, fault corrections or services). The aim is to have as little interruption time as possible per customer per

year. At the moment, the average level is 0.5–1 hour per customer per year. This means that a customer hardly ever undergoes a heat break more than once every five years.

The possible maintenance in district heating boiler plants and the boilers in Finland is one mainly during the summer time, one plant and/or one boiler at a time and the heat energy needed is produced by the other plants or boilers of the system. This is practical, because during the summer time the customers' need of heat is about 10–20 % of the winter peak heat load.

The Finnish network does not need much service because of the design decisions and operational principles that require only a minimum amount of additional water. The minor service needs of valves and other equipment are carried out with minimum heat breaks or during the operation. These kinds of service breaks last a couple of hours and are carried out quite seldom. Quite often, these kinds of service and maintenance actions are made during some other heat delivery breaks such as connections of new customers in that network area. This is possible among other things because of the loops in the district heating network, which enables the use of several supply directions and several different heating plants located at different sides of the customer.

The heat breaks caused by service, reparations and attaching new segments in the network can be shortened by:

- Looped net with several heating plants at different sides of the looped network
- Good planning and preparation of the service and repair tasks
    - Preparing of complete parts and subsystems before installation
    - Well planned and organised installation
- Long life time and good reliability of devices and components
- Good quality standard and quality control (for DH system design, construction and operation)
- Quality system and quality control for different parts and functions and operations of district heating system. It is essential to have high level quality control system in each part of the district heating system. Quality standards are not enough, also quality culture is required:
    - Equipment: It is not enough to have good quality norms. It is essential that production of equipment and systems obey these norms, regulations and requirements
    - Installation: It is essential to obey installation and construction introductions to ensure the quality and functionality of new equipment and systems. Poor installation quality easily destroy high level quality equipment. It is also important with technically simple systems like DH network.
    - Working methods etc. It is important to use proper working methods both during installation and operation period of energy system to ensure high quality operation and long lifetime of equipment and systems.

Development of operation and maintenance of Russian district heating system

Planning towards a customer oriented system includes a closed and indirect DH system. The need of a heating season and summer service period must be carefully analysed. An overall goal should be decided after which the optimisation of the different parts of the system would be possible. The new norm should, for example, include the following:

- Recommendations about DH quality systems
- Requirements of DH water quality (to prevent or totally stop corrosion and contamination inside the pipes)
- Requirement of equipment and material quality
- Quality system of production and quality control of production and installation components in district heating system

One of the main causes for this problem is the poor water quality in the Russian DH systems and enormous need of surplus water because of the open DH system. Oxygen and particles are significant problems and together they are almost catastrophic. Those cause the following problems:

- A lot of oxygen is always present in the DH water in Russia. That is because of the huge amount of additional water containing high oxygen content. This is the main reason for high corrosion levels.
- Enormous quantities of unwanted particles are added all the time in to the DH pipes
- Additional costs for water treatment and water heating
- Too many delivery breaks and losses because of not sold heat

Emptying the pipes and plants during the summer period increases following two problems:

- Oxidising is increased when pipes are empty
- Corrosion during summertime gives another aggressive part of excess material together with organic material (humus)

The main goal should be to have 12 months of heat delivery with maximum efficient use of fuel (city or town level optimisation) and high level environmental protection. Technically it will require:

- Development and use of combined heat and power production with maximum efficiency which minimizes the fuel consumption in the whole society.
- Closed and indirect DH system
    - Substations in every building i.e. ITPs or at least CTPs with heat exchangers must be installed.
- Water treatment sufficient for closed system
    - Requirements can be higher than in the case of open system but need of equipment is much lower than in open system
- No summer breaks
- Looped DH network
- Several heat production plants including at least one CHP plant to optimise the production

Other technical details must be presented in detailed norms or recommendations.

4.3 District heating network materials

Main questions related to district heating network are material strength, insulation, water quality and chemicals and other components in district heating water or other types of coating of the inner surface of the pipe.

DH network material requirements

All parts and components of the whole district heating system needs to be taken care of when the total system is planned.

The district heating system consists of the following parts (see next figure):

- Heat production units
- DH network
- Customer connection (substation and metering centre) and heating facilities in buildings

The DH network consists of two pipes: supply pipe and return pipe. These pipes are usually installed underground parallel to each other. Sometimes, the DH network is also installed inside buildings or on the ground. The latest option (on the ground) is used quite seldom in Finland. In bigger towns and cities, DH pipes are quite often inside the buildings in the city centre area, where buildings are built side by side (connected to each other).

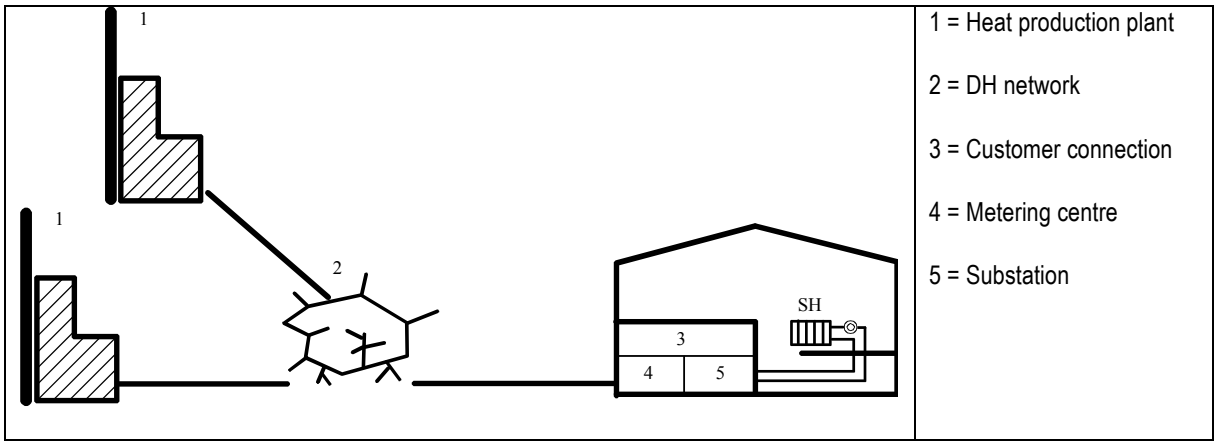


Figure 28: DH system [6]

The district heating network is an essential part of the system. It makes it possible to centralise the heat production in optimal production places. The DH network is also the most expensive part of the system. Technical requirements of district heating pipes, pipe elements and equipment are presented in Finnish district heating recommendations.

The type of steel, pipe wall thickness and all the minimum requirements are defined in the Finnish district heating recommendation. Basic requirements of pre-insulated DH pipes in Finland are as follows:

- Planning values
  - Planning pressure 1,6 MPa (16 bar)
  - Operational temperature ≤ 120 ºC
  - Heat carrier material: DH water with water treatment according Recommendation KK3 table 1.
- Pipes and components are according norms
  - Standard SFS-EN 253 Pipe elements
  - Standard SFS-EN 448 Prefabricated components
  - Standard SFS-EN 288 Valve elements
- General requirements
  - In normal operations and normal operational conditions, the life span of pipes and components must be at least 30 years, if the operation temperature is continuously 120 ºC and 50 years when the operation temperature is continuously 115 ºC. And if the operation temperature is less than 115 ºC, the life span must be over 50 years.
  - The manufacturer must give the installation, handling and maintenance introductions and guidelines for storages for the whole DH system and guarantee the operation of the DH network, if the design and installation are made according these instructions guidelines.
  - Expected life span should be achieved (temperature stress) if the maximum temperature is 120 ºC and occasionally 140 ºC
  - Pipelines must stand the mechanical loads with 0,5 meter filling
    - Stress of filling material
    - traffic load according Finnish norm RIL 144, load figure 3, load class 1 and 130 kN wheel load
  - Outside water proof up to 30 kPa (0,3 bar) pressure
- Outdoor temperature -18 ºC may not cause breaks into pipe element or change the shape or quality of the pipe element.
- Demand of quality assurance system (LT marked)
  - Pipe elements
  - Prefabricated components (valve elements etc.)
- Materials
  - Steel pipes according standard SFS-EN 253
  - Steel components standard SFS-EN 448
  - Cover pipes standard SFS-EN 253
  - Covers of components standard SFS-EN 448
  - Insulation of pipes
    - polyurethane according standard SFS-EN 253
  - Insulation of components
    - polyurethane according standard SFS-EN 253

Figure 29: Typical Finnish pre insulated and pre-fabricated district heating pipe

A new pipe under preparation for installation in a renovation of existing old damaged pipeline is presented in the picture. In this case the preparation of installation, for example pipe welding, has been done on the ground. Larger parts will be installed and final welding done faster to replace damaged pipeline.

An example of Russian district heating main pipe from boiler plant to town is presented in following picture. In this case heating and domestic hot water pipes are separate pipelines from boiler plant. This is a so-called four-pipe network. In Russia main pipes are quite often on the ground, while in Finland almost all pipelines are installed underground.

Figure 30: District heating main network in a Russian town.

Quite often there is a problem of insulation and pipe cover material in the Russian district heating network. This pipeline is installed underground only under streets and roads. A brand new district heating pipeline in a renovation of a Russian district heating network is presented in the following picture. It is essential to find out that the polyurethane insulation is without plastic or metal or any other cover material.

The following picture presents a prefabricated district heating valve element for pre insulated underground network. Valve elements may include other functions than only closing the valve. Sometimes emptying of the pipe needs air valves and filling valves installed in one combined valve element.

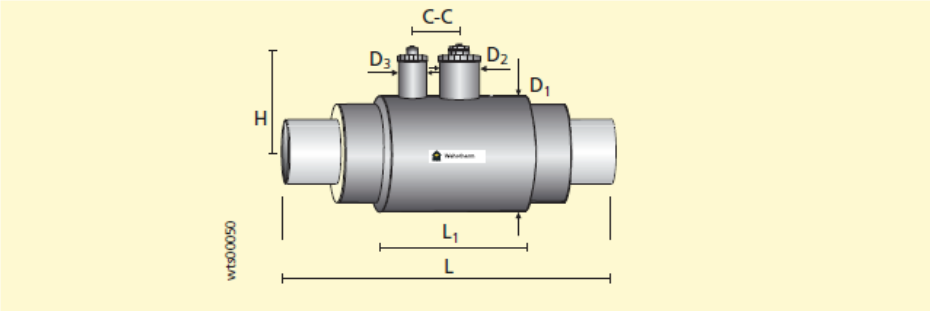


Figure 37: Scheme of a valve element [9]

The following picture presents two valve elements ready to be installed install in district heating network during a pipe renovation.

Figure 38: Valve element ready for installation

The valve is installed underground in pipeline. In this case only the stem of ball valve is on the ground in so called fake chamber.

The following picture presents a prefabricated fixing point of polyurethane insulated pre insulated district heating pipeline with a plastic cover pipe.

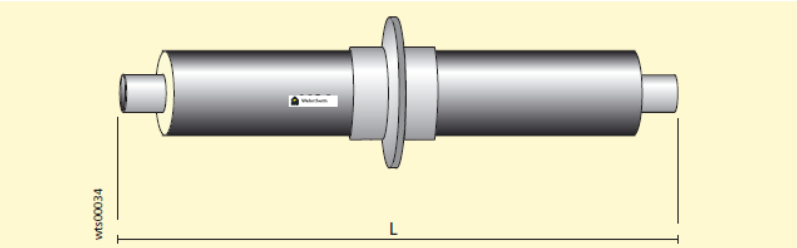


Figure 39: Fixing point [9]

In fixing point contains a steel element in pipe, which is cast in concrete fixing element under the ground.

4.5.2 Network Leakages

The main reason for leakages i.e. corrosion of DH pipes in Finland is the outside water reaching the steel pipe under the insulation material. This can happen only if

- There is outside water or humidity or
- There is some break or weak installation of a component or joint of a pipe.

Figure 40: Preparation of installation of district heating pipe renovation

The causes of leakages in Russia (and elsewhere):

- Bad treatment of district heating water and raw water is used as additional water in DH network.
- Outside humidity leads to wetting of the insulator and corrosion
- Outside mechanical damage
- Quality of the pipe material
- The movements of the ground around the network structure (quality of the excavation work)
- Quality of the pipe installation work
- Quality of the joint and insulation work

One reason for problems is damaged cover pipes, because of excavation work of some constructors. Those have nothing to do with district heating construction. They might be because of road construction or cable installation work. These failures can be avoided with a high quality map based information system. All excavators need to know the information and location of all the pipes and components.

4.5.3 Oxygen in open networks

One challenge in Russian district heating system is the open connection of domestic hot water (more information later in chapter 5). This means that hot tap water is district heating water and this open connection requires enormous amounts of additional water in to the district heating network every day. The following picture presents district heating water tanks, which are needed in a relative small town during domestic hot water peak consumption periods. Quite often peak demands are in the afternoon and also smaller peaks in the morning.

Figure 41: DH water storage tanks for domestic hot water peak loads in open DH system (50 m^3 each)

The huge amount of additional water requires lot of raw water and water treatment. This open connection means that lot of oxygen and other harmful materials will be added in to the district heating network every day. Oxygen causes significant corrosion problems and other materials are the main reasons for example for fouling of pipes.

Pumping costs

Pumping is one of the main variable costs components of district heating company. Only fuel costs and personnel costs are higher than costs of electricity for pumping the district heating water in network pipes. The following picture illustrates average pumping costs in some cities in Europe.

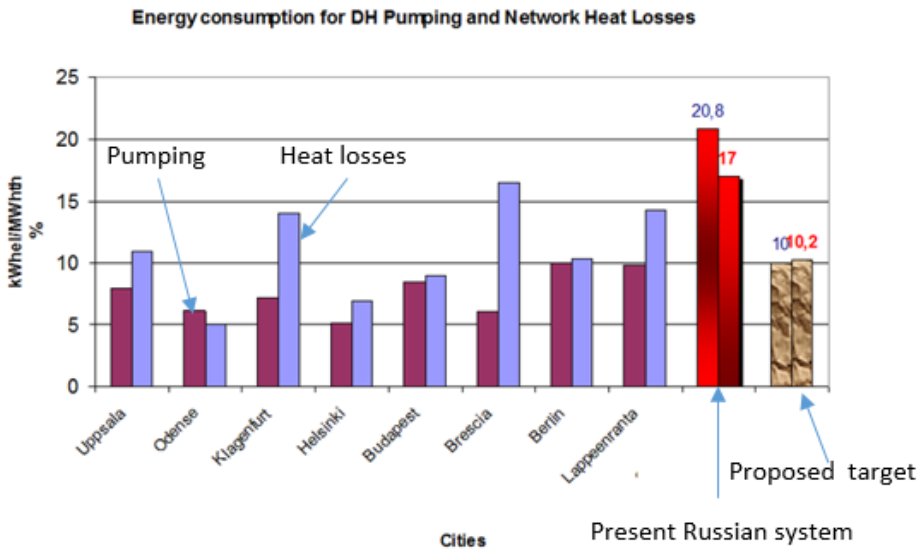


Figure 42: Energy consumption for district heating pumping and network losses in some cities.

The bars furthest to the right presents an example of a Russian district heating system pumping energy consumption (20,8 kWh_e / MWh_{heat}) and a reasonable target to save energy with optimal pumping arrangements (about 10 kWh_e / MWh_{heat}). The second value in the picture is the amount of heat losses is district heating system. In this example the actual figure in Russian system is 17 % and target again 10 %. Other bars present examples from some European cities as examples of values which can be achieved in district heating in Europe.

The following pictures present a reasonable solution for energy saving in pumping in one example case in Russia. The normal and only available operation mode in Russia is pumping from the CHP plant the whole need of pressure difference. Remarkable savings can be achieved with booster pumps in the system. Some existing heat only boilers can be connected to same network with the CHP plant. There is a possibility to build a one new heating plant with booster pump arrangement in the system. These renovations save pumping energy about 43 % i.e. from existing 20,8 kWh_e / MWh_{heat} to about 12 kWh_e / MWh_{heat}.

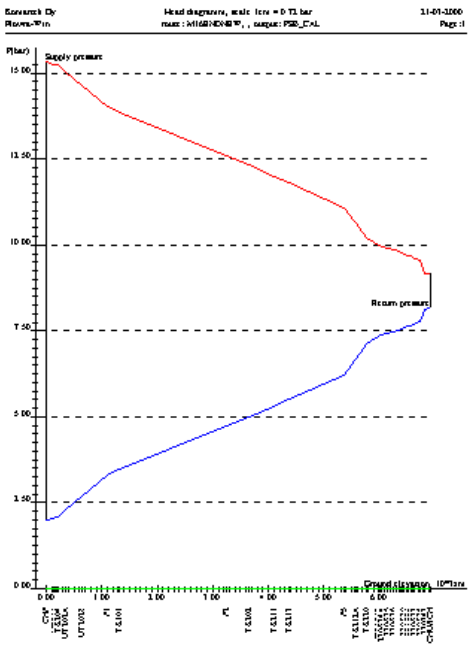


Figure 43: Pumping only in CHP plant

When the pumping is done only in CHP plant, the needed pressure difference is about 12 bar.

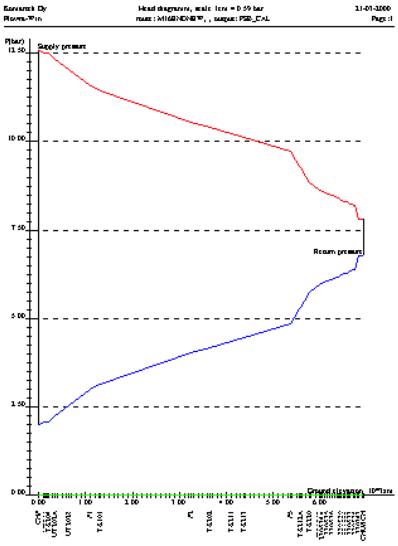


Figure 44: Peak and spare boilers as booster pumps

The difference of pressure difference is more than 2 bars.

The following graph presents the flow rates in different pumping plants in both cases i.e. only from CHP plant and using three booster pumping stations.

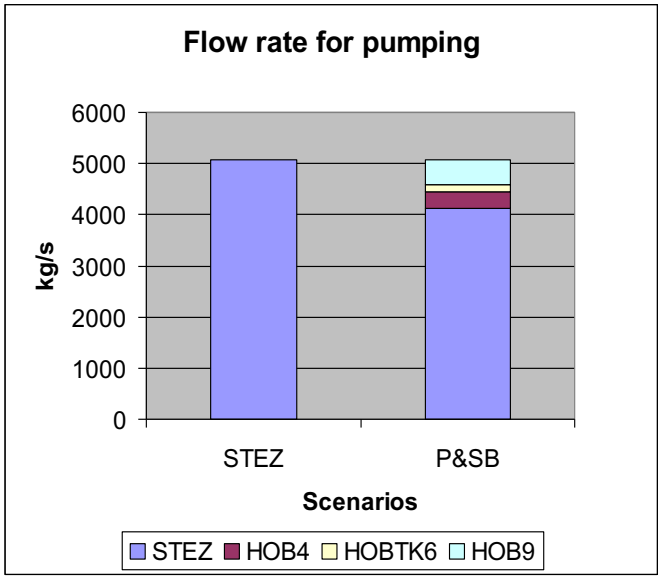


Figure 45: Flow rate of pumping

In the figure it can be seen that only 20 % of the flow rate is pumped by the booster pumping stations. As the following graph demonstrates the savings due to these arrangements can be almost 50 % in pumping energy.

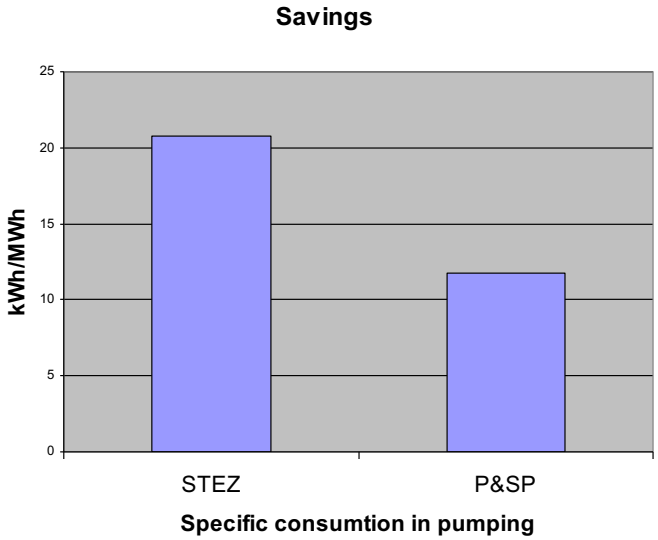


Figure 46: Savings potential in pumping energy with the use of booster pumping

It is clear that only with optimal use of booster pumping the need of electricity for pumping could be lowered more close to the European level. Other development possibilities are for example better cooling of district heating water and optimal district heating water temperatures. Temperature difference of district heating water is mainly related to the quality and condition of customer connection equipment. The flow temperature affects also to the cooling of district heating in two ways. First, too low temperature makes it impossible to have reasonable temperature difference. Too low flow temperature also raises the return temperature because of increased water flow through customer heating devices. All these lower the electricity production in CHP plant.

5 District Heating customer connection

There are several possibilities to connect a customer to district heating system. Connection can be done in building level i.e. individual connection or in regional level i.e. group of buildings (i.e. centralized level). There can also be a combination of those possibilities. There are also several possibilities to implement substation and its connection schema. Different solutions are possible in different systems like space heating, ventilation and domestic hot water production.

In Finland there has been national level regulation, which is a recommendation of district heating association about customer connection and district heating substation for several decades. In many other countries principles and techniques differ in different cities or even in different city regions. National level standardization helps all actors to work in district heating business. It is easy to design, install, use and maintain district heating sub stations. The following picture shows an old Finnish substation from year 1983.

Figure 47: Example of a typical Finnish district heating substation from 1980's

Substation in the picture is a building level substation and is located in an apartment building. Substation consists of heat exchangers and automation facilities and other equipment for space heating and domestic hot water production. All pipes and heat exchangers are well insulated and covered by plastic cover.

5.1 District heating customer connection schemas

In Finland district heating connection is always closed and indirect. District heating connection and substation are always located in customer level. Sometimes a bigger customer may have even more substations. This means that there is a substation and automation for example in every building in the site to improve the control and automation of each building.

There are two basic connection possibilities both in space heating and in domestic hot water production in district heating. Space heating and air conditioning can be implemented with indirect or direct connection schema (see next figure). Domestic hot water can be produced or delivered direct from district heating network, which means that hot water is district heating water in open connection. Another possibility is to use a heat exchanger between district heating network and domestic water system, when the connection is closed.

5.1.1 Space heating

There are two main possibilities of space heating system: direct or indirect district heating connection.

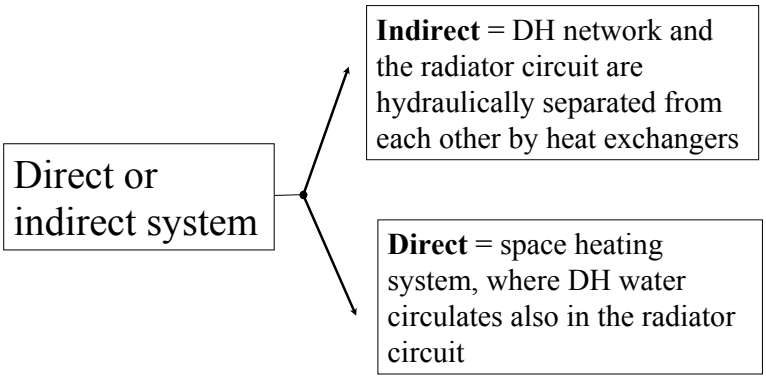


Figure 48: Direct or indirect DH system

An indirect system with heat exchangers between DH network and customer heating network (radiators) is safer than a direct system. It allows the use of higher pressures and temperatures in the DH network without hazard risks in the customer side.

5.1.2 Domestic hot water

Domestic hot water connection can be either open or closed (next figure).

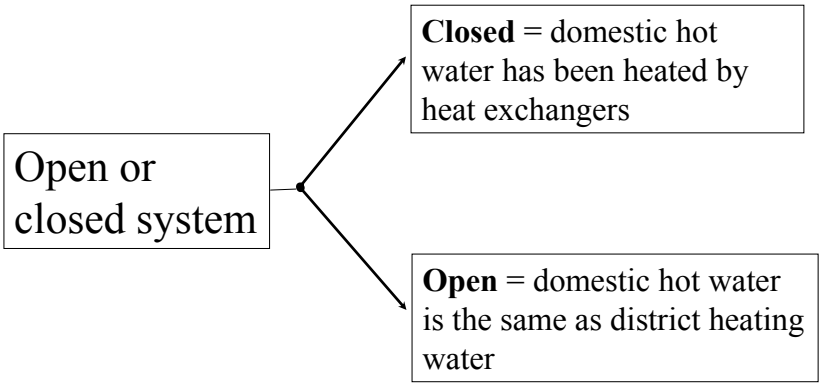


Figure 49: Open or closed DH system

In open systems, the DH water is used as hot tap water, which is a health risk for inhabitants. This is because of the water quality and high temperature as well as the pressure of DH water. District heating water quality is never as good as the quality of domestic hot water. In a closed system the quality problems of district heating water cannot reach hot tap water and inhabitants. High tap water temperature is also a health risk. Hot water may come out from the tap in steam form, which can cause burn injuries to people. High pressure increases the risks of steam and high temperature water from tap. High pressure can also damage pipes and other components inside the buildings.

In closed systems, it is easy to prevent water quality problems in DH pipes because the amount of additional water increasing into the network is much lower. This means less corrosion and less harmful material gets into the pipes.

Of course, there are several other options, for example:

- How the substation is arranged
  - Building level (ITP)
  - Regional solutions (CTP).
- How the heat delivery network is arranged
  - Two pipe system
  - Four pipe system
- Type of heat production facilities
  - Hot water boilers
  - Steam boilers and heat exchangers

This chapter includes the main features of the customer connection schemas.

5.1.3 Finnish closed and indirect connection schemas

In Finland the basic district heating connection is always an indirect and closed connection. An example of prefabricated substation is presented in following picture. The main components of substation are separate systems for space heating and domestic hot water production. Both systems consist of heat exchangers, automation systems, required pumps, valves and safety equipment. Also the needed measurements for indication and automation systems are an essential part of a prefabricated substation. Other components can be seen in the figure.

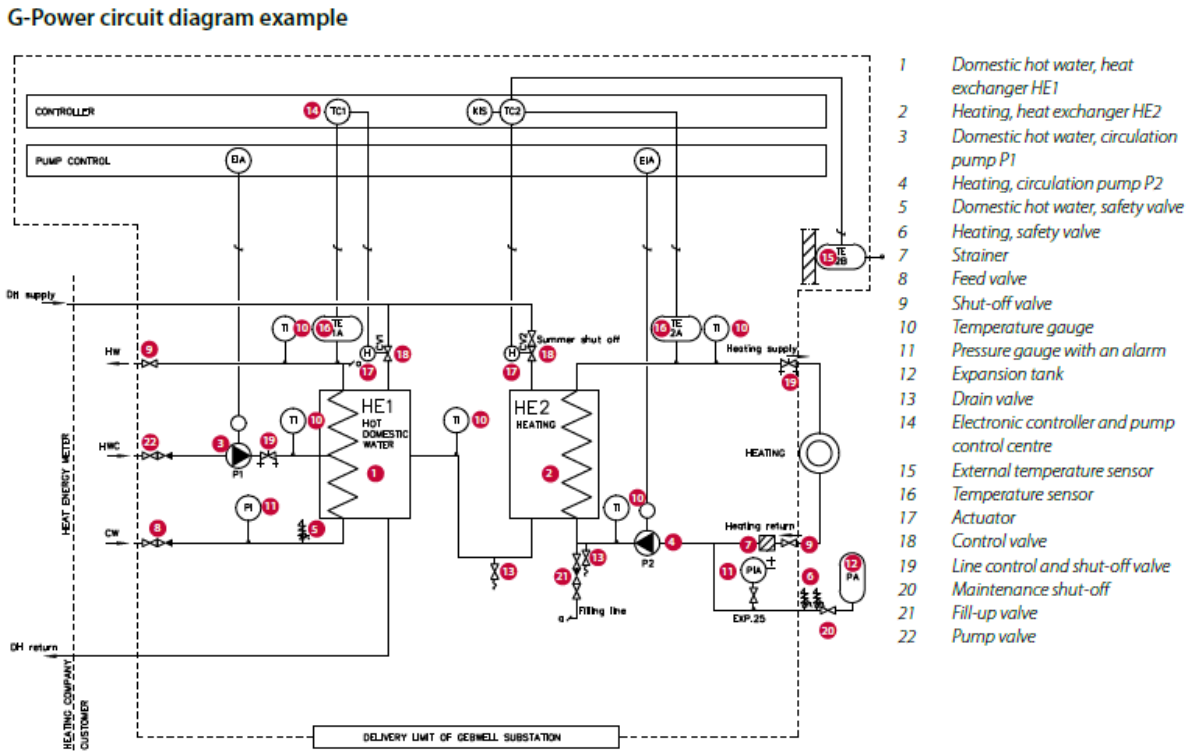


Figure 50. Indirect Connection Schema for District Heating [24]

The following figure a Finnish prefabricated district heating substation. A substation contains all equipment and components presented in the previous picture. Prefabricated substation is ready to be installed in to the building. All substations in Finland are designed and constructed according to Finnish district heating recommendation K1 [29].

Figure 51: District heating substation [24]

A substation can be installed also on the wall. This is often the case of small units. Heavier substations will stand on the floor as can be seen in previous picture. The following two pictures present examples of hybrid heating systems implemented together with district heating is building level connections.

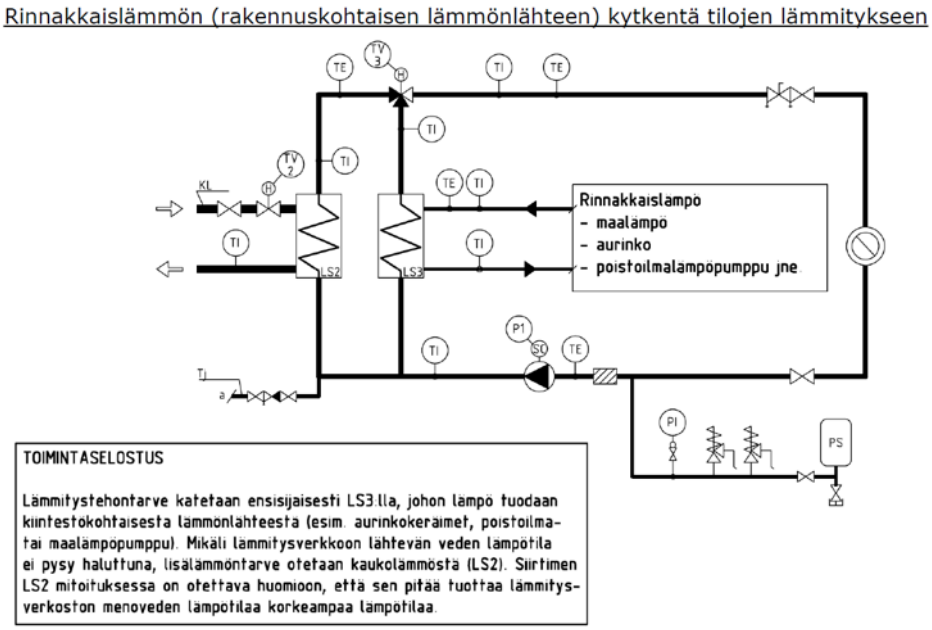


Figure 52: Example of a hybrid connection to space heating [29]

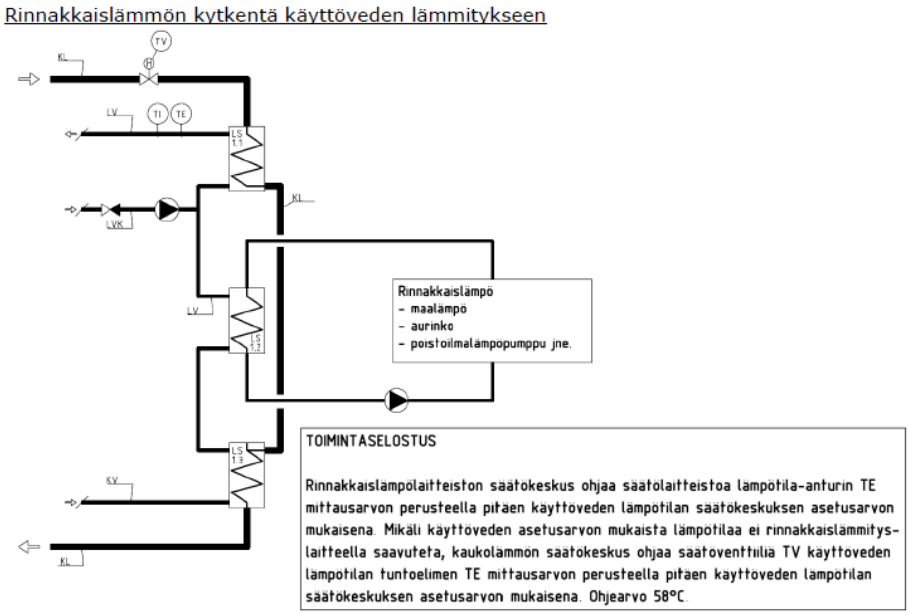


Figure 53: Example of a hybrid connection to domestic hot water production [29]

5.2 Problems of direct connection of district heating in buildings

In direct connection systems, the district heating supply temperature must be kept low because the same water goes into the apartments through radiator network pipes. This has both positive and negative impacts. It causes less heat loss in the supply pipe. Because there is a lack of control facilities and no adjustment of the flow rate in the buildings, the return temperature is very high. This increases the heat loss in the return pipe while the temperature is almost 80 ºC instead of 40 – 50 ºC level, which is normal when there are modern customer oriented substations in every building.

The main disadvantages of direct heating connection are as follows:

- Lack of proper control system, which causes huge waste of heat energy
- Risks in pipe or radiator breaks
  - High DH temperature (health risk and material risk)
  - High DH pressure level
  - Huge amount of water in DH network, which increases the risks and sizes of material damages and human injuries because of leaking hot water

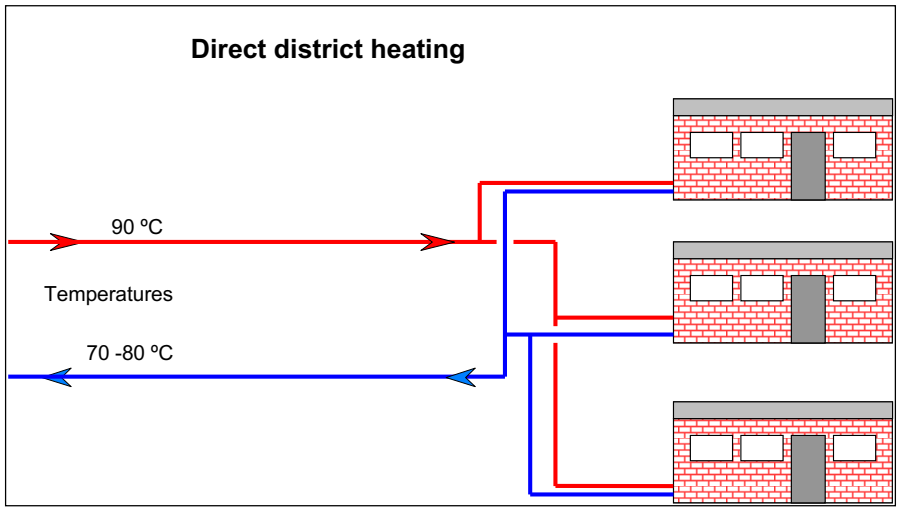


Figure 54: Direct DH system

The Finnish recommendation is based on having individual substations in every building. The connection scheme is presented in the next figure [32].

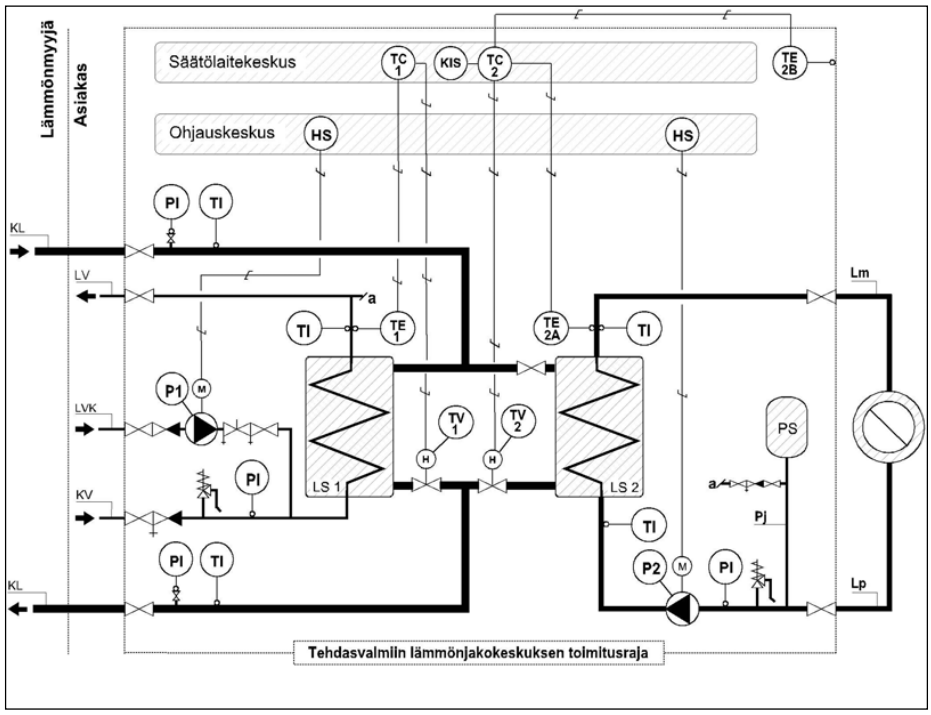


Figure 55: Connection Schema of Finnish district heating substation [32]

Figure 55 displays a substation for a single family building. The main features include separate heat exchangers and automation facilities for both space heating and domestic hot water. In Finland there are separate heat exchangers for each individual heating purpose (air conditioning, swimming pool etc.).

Plate-type heat exchangers are used for individual substations. Having the same technical parameters, the heat exchangers can be 3–6 times smaller than the tube-type heat exchangers. The weight of the plate-type heat exchangers is only 1/6 of the tube heat

exchangers. Their heat transfer characteristics are superior because they have many different advantages, such as allowing more heat energy to be saved as well as reducing initial costs by saving active areas.

Modern systems regulate heat consumption by individual, building level automation. As a minimum requirement, these systems have an automatic outdoor temperature based control program, which includes a clock and the timetable functions.

Solution possibilities for space heating

The main goal for space heating systems is to provide comfortable conditions for living in all outdoor temperatures. The technical solution to the problem could be the indirect connections with building level (ITP) or regional level (CTP) substations. At the same time, ITP must provide customers a possibility to control heat delivery automatically in accordance with the weather conditions and according to individual heat demand. According to energy saving aspects as well as the quality of control and the automation system, the building level substation arrangement is more effective and recommended.

CTP connection should only be used in some special cases when it is not possible to use ITP. It is also much better for organising the heat metering of each building in each ITP. In that arrangement, the heat metering of both heating and domestic hot water can be done with one heat energy meter.

The renovation of substations should be timed parallel with other investments of the DH system. The co-operation of the ejector control systems and direct heating systems with new installed substations should be ensured during the installation and renovation period.

5.3 Problems in heat exchangers

In Finland contamination or clogging of heat exchangers in district heating sub stations has not been a problem. But in recent times there have occurred some cases in which heat exchangers, which have been in use only a few years, have clogged. A research project was conducted to find out 3/ how usual it is that heat exchangers in sub stations clog, or if there occurs other limitations in heat transmission, and find out the connecting threads of these cases and typical reasons for clogging.

The total amount of heat exchangers, which had some problems were very small. Only a few cases were found in the research project. The most common reason for problems is foreign substance in the system. This goes for primary side of heat exchangers as well as secondary side. In some cases occurs mounting faults for example in lines which connect buildings to the main district heating line. Faults in commissioning of the pipeline and installation work can cause many problems, especially if the pipeline flushing has been neglected.

The problem of foreign material in secondary side seems in some cases to relate to inhibitors and chemicals used in heating water. No individual inhibitor or chemical was named or individualized in the project as a reason for problems. Problems occurred as well in new systems as in old ones. On the ground of this study in can be discovered that using or chancing of inhibitors must be carefully considered especially in old heating networks.

One reason for the limitation of the heat transmission is oxygen dissolved in heating water. Heating pipes which are made of steel are in better condition than pipelines made of steel and plastic pipes and accessories. Oxygen dissolved in water causes corrosion inside steel and copper pipes. Corrosion products sometimes find their way to the heat exchanger and clog it.

In this study no references that heat exchangers clogging have become more common in Finland were found. Most cases are individual and new cases will be found in future.

One problem in the primary side of the heat exchanger was caused because of wrong installation of customer connection pipe. Problems were indicated in cases where the customer connection pipe was installed below the main pipe. The correct installation is presented in the next picture.

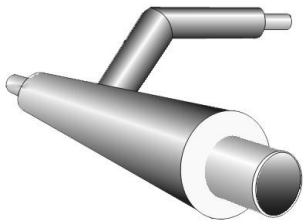


Figure 56: Correct installation of the customer connection pipe [9]

This assembly does not allow the foreign material from main pipe to flow to the connection pipe and customer heat exchangers. Also control valves must be saved from harmful materials like sand and welding residues etc. In addition this installation helps to prevent material flow from main pipe to customer connection pipe and to substation and heat energy meters etc.

5.4 Problems of domestic hot water with open connection

In Russia there is quite often an open hot water connection which means that the customers use the district heating water for domestic hot water. This is a health risk for inhabitants, because of the district heating water quality and high temperature and pressure of the district heating water.

In an open system there is a huge need for additional water in the district heating network, which causes problems for example with the water treatment system. Also, if the water treatment is not successful, there will be numerous problems with the DH pipes. In Russia there are frequent problems with pipes and especially with the corrosion of pipes. Lots of oxygen in water means fast corrosion. The amount of harmful material will increase greatly when a large amount of water is added into the pipelines. Corrosion and other unwanted materials not only cause corrosion but they are also a health risk. As a conclusion, the following risks and problems are due to open domestic hot water district heating systems:

There are some different causes of health risks because of open district heating system

- Domestic hot water temperature can be much too high. This is mainly because of poor temperature control of domestic hot water. Risk of getting high DH temperature water or even steam from taps because district heating water temperature varies from 90 to 150 °C.
- High water pressure in tap pipes. This means risks of leakages and also high flow rates from pipes. With temperature problems these can cause steam flows from taps.
- High level water quality is important in domestic hot water
    - Chemicals used in district heating water treatment can be harmful for human beings
    - Corrosion material of district heating and hot water pipes will be in domestic hot water and those can be very harmful and risks for health
    - Other unwanted material in tap water can cause health risks and other problems

There are also other risks like for example network risks

- High rate of corrosion because of huge amount of added water in network
- Scale can block the pipes

Other risks related mainly to technical systems and equipment

- Water treatment system needs to handle a lot of water
- Water quality problems in boilers and heat exchangers in power plants
- In every leakage in building networks there is always whole DH network water amount in same pipe system and the size of a leakage can be huge.
- Corrosion material and other unwanted materials cause problems to every component and equipment in the system and lower the lifetime of these components.

In an open system there is a huge need for additional water in the DH network, which causes problems to the water treatment system and pipes. At least 20-30% of the initial water is used for these purposes. As a result, there is a lot of oxygen in the DH systems which supply hot domestic water. This means fast corrosion and a short (3-15 years) life span for the pipelines.

In the Finnish DH system, there is always a heat exchanger for domestic hot water in every building (see previous figures in chapters 5.1 and 5.2.)

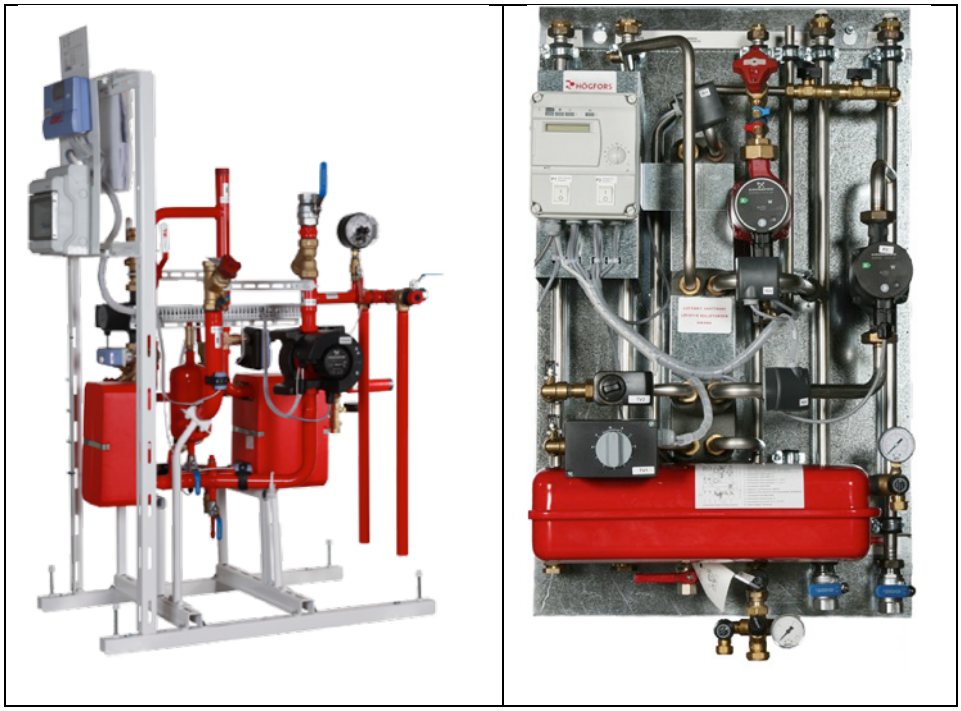


Figure 57: District heating substation left: apartment building, right: one family house [14]

In a closed system, it is easy to prevent water quality problems in DH pipes because there is a much lower amount of water increased into the network. The average value of new water is less than 1% compared to the Russian open system. That means there is less corrosion and less harmful material entering into the pipes. These are the main reasons for a longer life span of DH pipes (average is over 30 years).

Development of domestic hot water connection in Russia

It is recommended to install building level substations (ITP) with domestic hot water heat exchangers and automation in each building. The second possibility is to use regional substations (CTP) but the quality of control and energy efficiency is not as high as in building level substations (ITP). In every case the substation has to include heat exchangers to separate district heating water and building level networks.

New connection schemas need proper planning and design. Both space heating and domestic hot water should be planned and implemented at the same time.

There is one remarkable problem with the hot tap water renovation. It must be ensured from the local water company that there will be enough water available coming through existing cold water pipes for hot water as well. If there is not enough water available, there will be a need for a water pipe renovation or extra pipeline installation.

During the other substation renovations, the delivery network should also be analysed and renovated, because after these changes, the expected life span of the DH pipes will increase dramatically. One renovation should be to change the 4-pipe systems into 2-pipe systems, which means, that domestic hot water is produced in each individual building (in ITP) and not in a boiler plant.

5.5 Control and Automation System (CTP Level)

Basic function of substation level automation is to ensure sufficient amount of heat for space heating, air conditioning, domestic hot water production and other heating purposes. Substation has important impact on the quality of district heating system for the customer and also for district heating company.

Instead of building level substations (ITP), which are more or less the only solutions in Finland, there are quite often regional substations for a group of buildings. There are some significant problems in the Russian district heating system based in the central substation (CTP). The following picture illustrates a typical type of CTP solution in Russia.

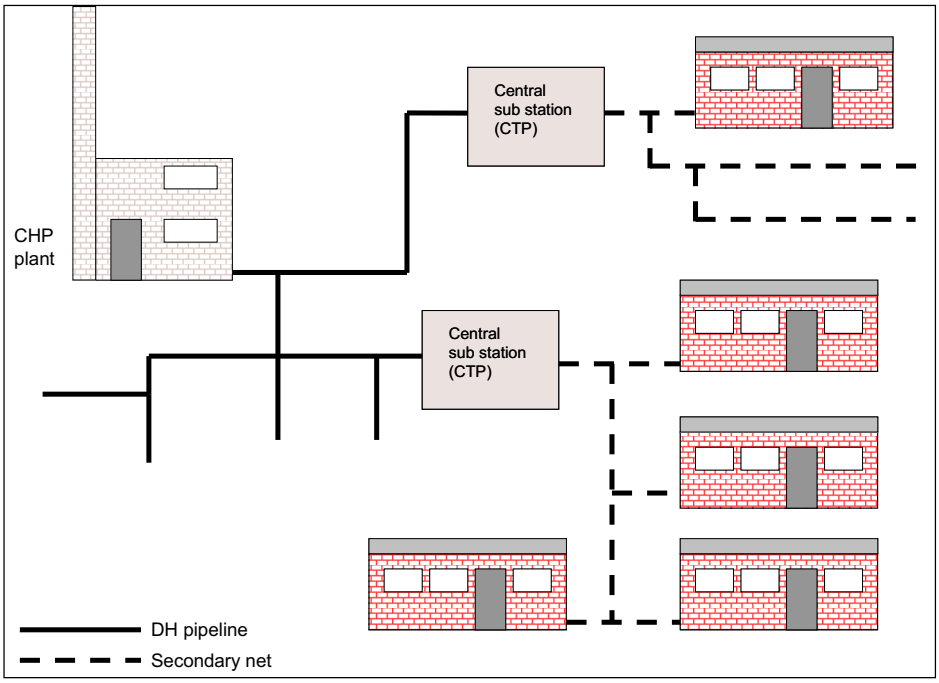


Figure 58: The Russian district heating system with central substations (CTP)

The figure illustrates both district heating network and the secondary network from substations (CTP) to buildings. District heating water flows in secondary network if there are no heat exchangers in substations. In Russia there are sometimes different organisations operating district heating and secondary networks.

District heating CTP systems are the middle chain in the production, delivery and consumption system. Its aim is to prepare, distribute and deliver heat and hot water to the group of buildings. This type of distribution system is less effective and causes more heat losses than the building level (ITP) system because of the lower quality automation, which does not allow the possibility to control the individual use of heating energy (i.e. building level).

Building heating systems are connected into CTP through correction mixing pumps (dependent scheme with ejectors inside the building) or through heat hot-water heat exchangers (closed connection scheme).

Typical features of the system in the picture:

- The basic feature is that there is only one heat production plant in each DH system. This is also the case with individual substations (ITP).
- The heat to the quarter of apartment buildings or to buildings of one industrial customer is supplied through CTP (central substation).
- It is planned that a CTP will have all the components needed in adjustment and control of heat use.
- CTP does not operate properly in normal operations; there are problems with temperature control, cooling of DH water, lack of heat energy measurement etc. This means mainly no meter or at least no metering in building level.

The scheme decisions of CTP, automatic controlling and operating goals, have different working orders in different theoretical cases and they depend on many factors. In practice, it is always easier to operate with building level automation and heat exchangers than with larger regional ones.

The following diagrams illustrate typical CTP systems and the actual temperature levels of space heating.

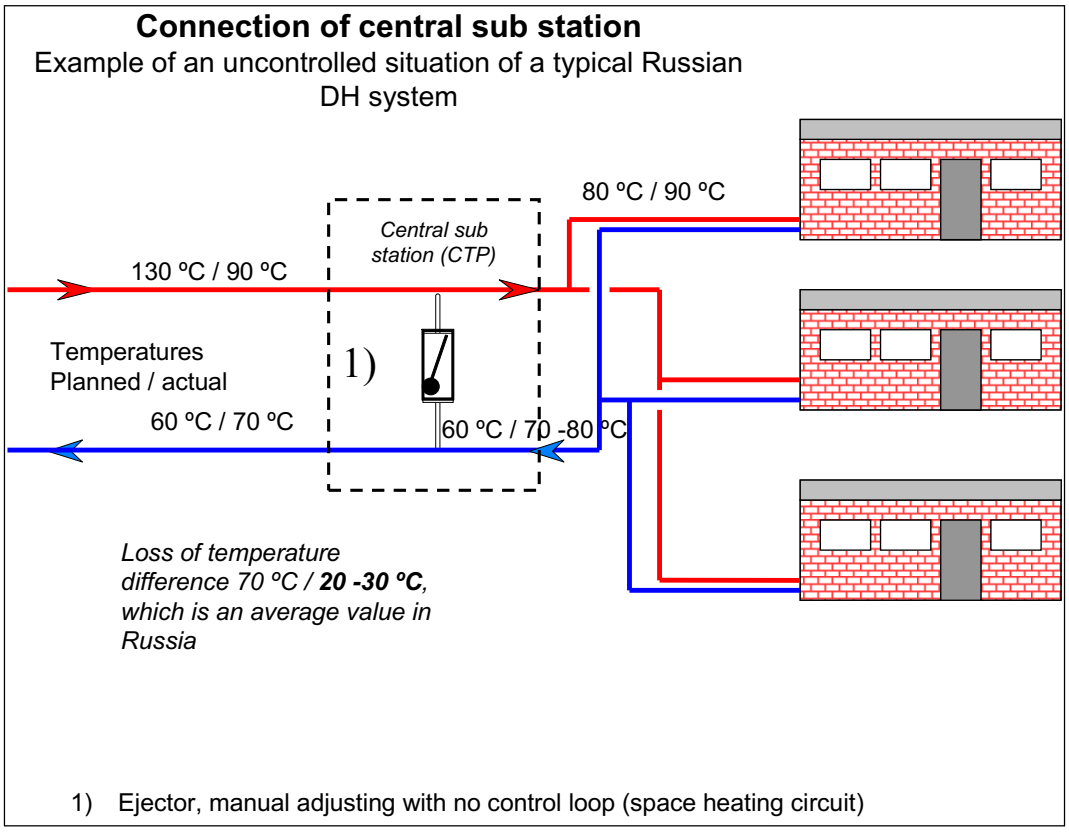


Figure 59: The Russian arrangement of CTP for space heating

The network from CTP to each building is so called the 4-pipe system. Quite often, the automation and control system as well as the heat metering facilities are not in operation in the CTP even they might be installed in the substation. This is one of the reasons for the very low cooling of the DH water in those Russian DH systems. Low cooling of DH water means that the DH pipes in the network have lower heat carrying capacities. It also causes a lot of extra pumping costs and extra heat losses in DH network.

Control of heating network temperatures in buildings i.e. indoor temperatures of apartments, is never as accurate in CTP as it is in ITP. CTP has longer pipelines from the control point to the apartments, in addition to the difficulties it has in balancing the heating network (system). This also causes more heat losses and lower cooling of the DH water, as there is a need for overheating to ensure heat for each apartment.

In Russian DH systems, the cooling of DH water is not 60-70 °C as planned. The normal value is 20–30 °C. Electricity consumption for pumping in Russia is twice the value in Finland. In Russia the electricity consumption is about 20 to 25 kWh / MWh district heat from production. In Finland the average value is about 10 kWh / MWh.

According to Russian experiences each connection scheme and principle has its own theoretical and sometimes practical sphere of use. The main disadvantage of the CTP connection is the customer heat delivery group regulation. It can be seen as an inefficient regulation of heat delivery during the transitional heating season. In order to keep the necessary temperature during this time, water temperature in hot water systems must be much higher than it is required for heat systems. The operation task in these conditions is to avoid overheating the building by the heat delivery regulation. This is mainly a problem related to connection scheme and automation and control facilities. During the cold heating season, network water temperature can be lower than required because of heat resource damages, lack of fuel or low outdoors temperature. In these extreme cold winter weather circumstances, the operation task is to avoid heat network overload. If the water temperature is too low, CTP temperature regulation valves become completely open and control capability is missed. Heat networks from CTP to buildings are made of four pipes; it consists of supply and return

pipelines for heat and hot water delivery. This requires a large amount of investments and huge heat losses as well as high electricity consumption for pumping. The risk of systems damaging, especially for hot water pipelines, is much higher than for trunk pipeline. [1]

In Finland there are no centralised substation systems (CTP) or to rephrase, there are only insignificantly few centralised substation systems in Finland. There used to be some in the 1960s and in the beginning of 1970s, however, almost all of them have been renovated into building level substations (ITP) during some other renovations in the district heating or heating systems in those buildings.

In the Finnish DH system, there is always a heat exchanger for space heating and domestic hot water production in every building (see for example figure 57 in chapter 5.4.). Automation of space heating contains the following parts:

- control unit
- control valve with actuator in DH circuit
- supply water temperature sensor (radiator network)
- outdoor temperature sensor for adjusting the heating temperature curve

With this arrangement, the temperature of the customer radiator network supply water can be automatically adjusted to the required level in every outdoor temperature condition.

Extra accuracy can be achieved with room temperature sensors i.e. an indoor temperature sensor can inform the system about the indoor temperature of the most important rooms.

Domestic hot water is mainly produced in CTP by using a huge pipe heat exchanger or an open system (which is used more often), where DH water is used directly as hot tapping water.

Solution for space heating automation in CTP

In the CTP system, the control of the heat demand and the use in each individual building is never as good as in the ITP solution. That is why ITP is recommended every time it is possible to be installed.

The following figure illustrates a solution for heating circuits. This solution solves the adjustment of the temperature, the cooling of the district heating water and the safety of the radiator network and hot tap water.

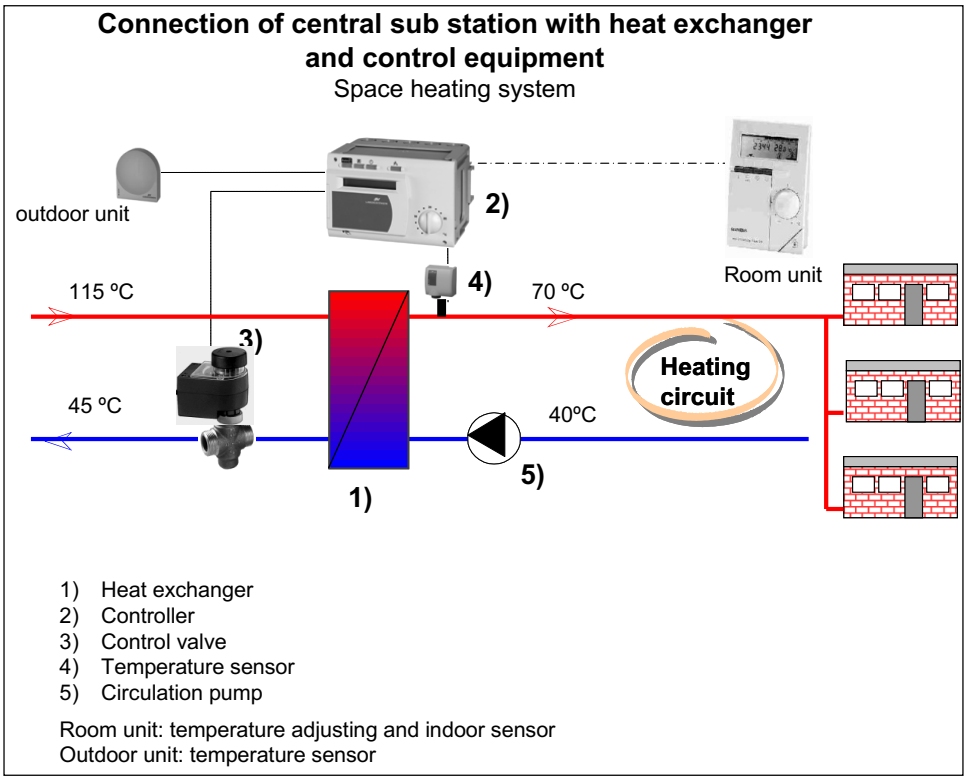


Figure 60: CTP space heating system equipped with heat exchanger and automation [1]

During the renovation of the CTP, an installation of the heat exchanger and the automation facilities should occur as presented in the previous figure.

- heat exchanger
- circulation pump for radiator network
- radiator network temperature control: controller, actuator, control valve (in DH return pipe) temperature sensor, outdoor temperature sensor
- radiator water expansion tank and expansion valves

Additionally, in the renovation process, automation and heat exchangers for domestic hot water heating have to be installed into the CTP. In that case, it has to be assured that there is enough cold water available from water network in order to produce warm tap water as well. This is because the warm service water was originally taken directly from the district heating network and water network has been planned to serve cold tap water requirements.

In the CTP system, the control of heat demand and use in each individual building is never as good as it is in the ITP solution.

Obviously, it is more reasonable to use ITP systems with two-pipes distributing system instead of the existing CTP and four-pipes distributing heat system. That is why ITP is recommended every time it is possible to be installed.

By installing the completely automated ITP with plate-type heat exchangers, a calculation system and an automatic weather controlling heat delivery system, it is possible to avoid many of the disadvantages listed above. Switching to a two-pipe variant of heat supply offers the following advantages:

- Total length of pipelines can be shorten twice, i.e. metal consumption decreases for 30–50 %
- Investments into heat networks as well as construction and heat insulation costs decrease for 20–25 %

- Heat losses inside district network decrease, electric power consumption for heat-carrying agent transit also decreases for 20–40 %
- Because of automation regulation of heat supply to concrete customer (building) heat economy for space heating achieves 15 %
- Construction time is shorter

5.6 Problem of insufficient district heating capacity of a customer

The indication of a problem when the DH capacity is not enough for a customer is when the indoor temperature is not sufficient enough (i.e. is too low) during the year, most notably during the coldest winter period.

Possible reasons for that problem:

- Production capacity is not sufficient
- Not enough DH pumping capacity
- DH substation of the customer has enough capacity. Reason may be heat exchangers, control valves etc.
- DH delivery network is not in proper condition or some pipes are too small. There might be leakages of pipes or the insulation of pipeline is damaged or even stolen.

Most often, heating companies and consulting offices think that the reason is the boiler plant being is too small or the power plant capacity or pumps being too small.

Most often, the reason is due to some minor part of the network and sometimes it is due to a lack of production unit optimisation.

If there are problems of insufficient heat delivery, the whole DH system should be analysed, including:

- total customer heat demand
- heat production capacity (also partial load analysis)
- network analysis
    - hydraulic calculation
    - analysis of pumping

Problems because of pipe leakage

- pressure difference is not enough for customer even pumping is working
- wet insulation → increased heat losses → too low temperature for customer

If the DH network insulation is badly damaged or wet, the heat losses from network increase so badly that it might be difficult or even impossible to serve enough heat to some remote parts of the district heating network.

6 Heat Metering

Heat measurement is an important part of a modern and effective district heating business. With a proper measurement system, a district heating company can be sure that all the consumed energy will be invoiced and every customer will pay only for the amount of energy they use.

However, the district heating company is responsible for all the network water and heat losses, and these cost components must be considered in the tariff system. It is also important to have a sufficient measurement system for optimizing and operating the heat production and delivery systems, in order to determine the heat losses and efficiencies of the system.

Correct measured data is an important basis for optimization of energy and district heating system. It is essential both for production and delivery systems. The following picture presents an example of a district heating metering centre.

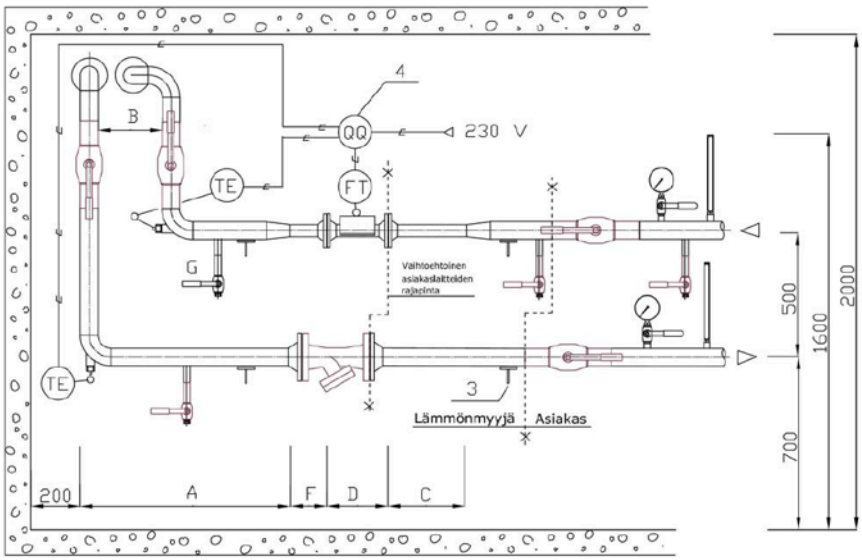


Figure 61: District heating metering centre [12]

In the measurement of district heating energy consumption there are three different parts [4]:

- flow meter for water flow rate measurement
- temperature measurement of supply and return temperatures of district heating water to calculate temperature difference of district heating water
- calculator for calculation of consumed heat energy according temperature difference and water flow rate

The main features of district heat metering centre are as following:

- Flow meter in return pipe. It is possible to assemble a flow meter into incoming (hot) pipe, but the there is a need for a special type of heat calculator.
- Sufficient length of straight and undisturbed pipeline before flow meter to prevent measurement error caused by unwanted changes of flow profile.
- Return pipe below the coming pipe because it prevents the insulation to wet during flow meter repair or renovation.
- Always a strainer before heat meter, especially if mechanical flow meters are used.

– The main valves of heat company are in the metering centre
– The border between heat company and customer are in customer's ball valves straight after metering centre. (see picture 61)

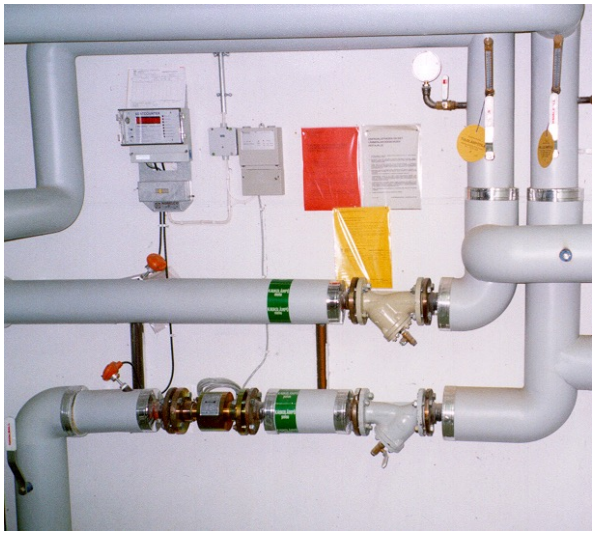


Figure 62: Picture of a large office building in Finland

6.1 Flow meters

Main flow meter types in Finland are magnetic type flow meter and ultrasonic flow meter.

6.1.1 Magnetic flow meter

In the figure 62 the flow sensor is a magnetic flow meter (Enermet 10 EVL). Magnetic type flow meter became very popular in Finland in the 1980s and in 1990s. Mechanical flow meters were used in early years of district heating. But they were not accurate enough and the actual lifetime was sometimes quite short. Later also ultrasonic flow meters became widely used. Mechanical flow meters are used very seldom today. The operation principle of a magnetic flow meter is presented in following figure.

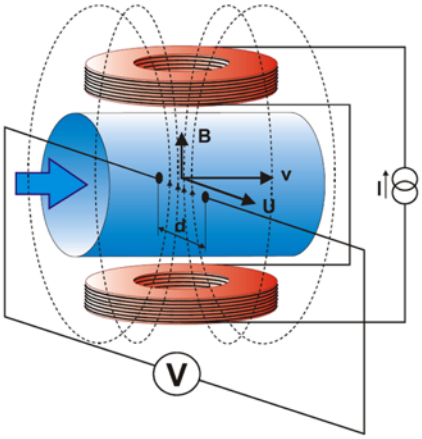


Figure 63: Principle of a magnetic flow meter [27]

A magnetic flow meter is used for measurement of flow volume of electrically conductive liquids. Measurement principle is based on Faraday law on electromagnetic induction. A sensor consists of a non-magnetic tube with non-conductive lining, measuring electrodes and two coils generating electromagnetic field. Flowing liquid forms a conductor. Magnetic field induces voltage in this conductor that is proportional to magnetic induction, distance between electrodes and flow velocity. As magnetic induction and distance between electrodes are constant, induced voltage is proportional to velocity of liquid flow in the tube. Volume flow rate can be calculated from flow velocity and tube cross section. [27]

The cutaway of a magnetic flow meter is presented in following picture. The non-conductive lining inside the tube can be seen in the picture. Two electrodes are located at opposite sides of the flow tube.

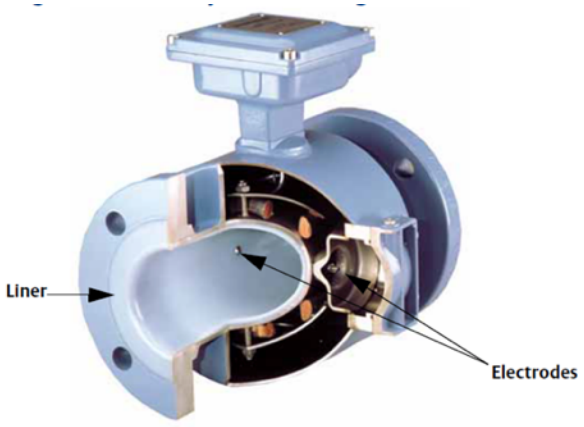


Figure 64: Cutaway of a magnetic flow meter [28]

Some unwanted coating (magnetite for example) inside the magnetic flow meter can change the electrical behavior of the meter or changes the inner diameter of the flow pipe. Both may cause measurement error in flow measurement. Inner coating increase the velocity of water in the meter and thicker layers may influence on the error of the measurement.

Advantages of magnetic flow meter

The principle is virtually independent of pressure, density, temperature and viscosity. Even fluids with entrained solids can be metered (e.g. ore slurry, cellulose pulp). Large nominal-diameter range available (DN 2...2000). Free pipe cross-section. No moving parts. No pressure losses [35]

6.1.2 Ultrasonic flow meter

Another important type of flow meter used in the district heating systems is the ultrasonic flow meter presented in the following picture. Ultrasonic flow meters are used both for consumers and heat production plant measurements the same way as magnetic flow meters.

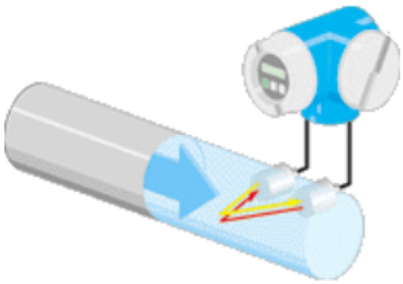


Figure 65: Operation principle of an ultrasonic flow meter [34]

Ultrasonic pulses go faster with the flow than against the flow. Ultrasonic flow measurement is based on this elementary transit time difference effect. Two sensors mounted on the pipe send and receive ultrasonic pulses. At zero flow, both sensors receive the transmitted ultrasonic wave at the same time, i.e. without transit time delay.

When the fluid is in motion, however, the waves of ultrasonic sound do not reach the two sensors at the same time. This measured "transit time difference" is directly proportional to the flow velocity and therefore to flow volume. /34/

Advantages of ultrasonic flow meters

There is no contact to flow from outside. It is ideal for measuring highly aggressive liquids or fluids under high pressure. With homogeneous fluids, the principle is independent of pressure, temperature, conductivity and viscosity. There are no pipe constrictions, no pressure losses, no moving parts and no disturbance to the flow profile /34/. In the following picture some typical ultrasonic flow meters which are used in district heating are presented.

Figure 66: Ultrasonic flow meters [30]

There are several types of arrangements of ultrasonic sensors of flow meters. Sensors can be parallel or in opposite sides of the pipe. Sometimes in smaller flow meters there might be special pipe arrangements inside the flow meter. The following picture presents one type of a small flow meter specially designed for one family houses and other small buildings.

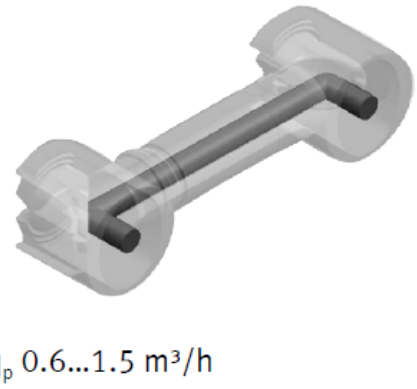


Figure 67: Small size ultrasonic flow meter [30]

This kind of pipe arrangement makes it possible to achieve a longer route for ultrasonic pulse to improve the accuracy of flow measurement. If the route is short the transit time difference is short and the measurement inaccuracy increases. Another reason for the construction is the better quality flow velocity profile. A disturbance of the profile lower the accuracy of flow rate measurement.

Pressure loss of flow meter is one important feature of metering devices. Many manufacturers say that ultrasonic flow meter or magnetic flow meter does not influence pressure losses. In practice the inner diameter of a flow meter is smaller than the pipeline in metering center, because of the needs of measurement accuracy. That is why flow meters quite often cause reasonable pressure losses. The following picture presents a pressure loss chart of one typical type of ultrasonic flow meter.

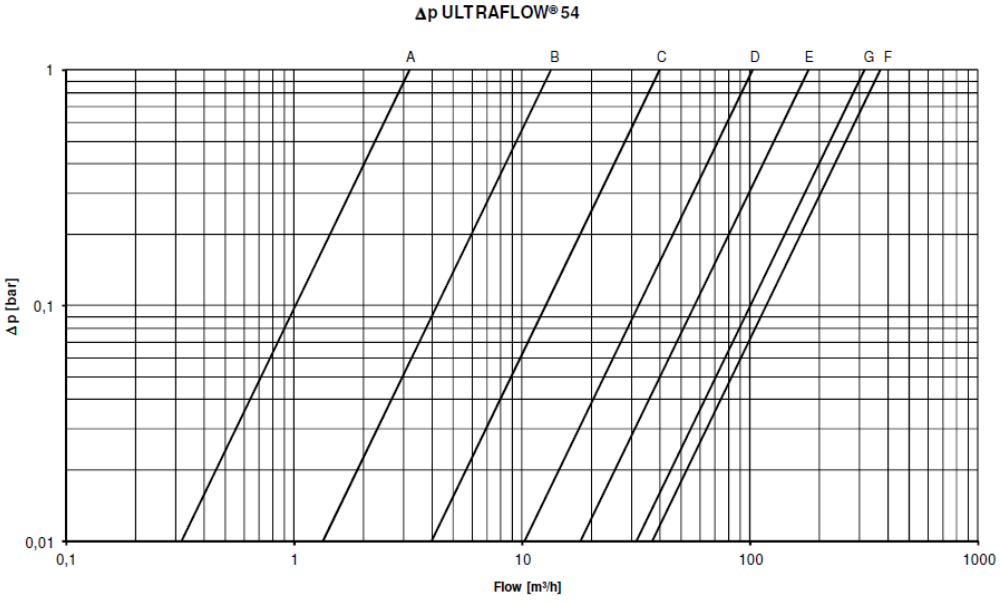


Diagram 1. Pressure loss chart.

Figure 68: Example of a pressure loss chart.

6.1.3 Installation of flow meters

Proper installation of a flow meter is essential to achieve high level measurement accuracy and minimum error of metering system. Installation principles of flow meters are presented in following pictures [33].

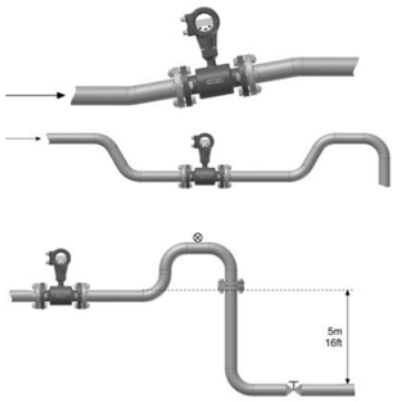


Figure 69: Installation principles of magnetic type flow meters [33]

It is important to keep the flow meter all the time filled with water.

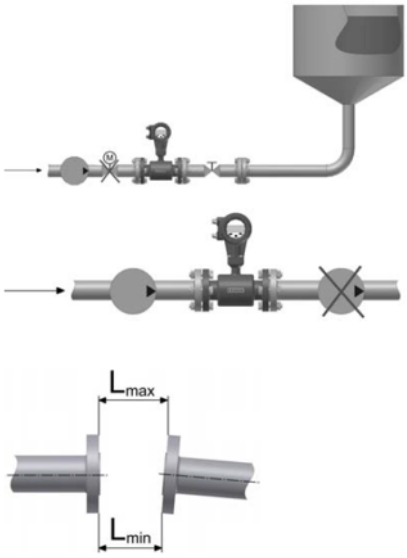


Figure 70: Installation principles of flow meters (2) [33]

Most of the flow meters are designed to operate in fully developed turbulent flow velocity profiles. It is important to prevent all types of disturbances of flow profile before the flow meter. Some flow meters do not need any straight pipe in the inlet of the meter because of the inner construction of the meter. Some solution for that is a reducing fitting of flow meter. A reducer helps to prevent flow disturbances. In every case however, it is essential to install meters as well as possible. The installation should always be done according the instruction of meter manufacturer. In following picture an example of guidelines of a meter manufacturer is presented.

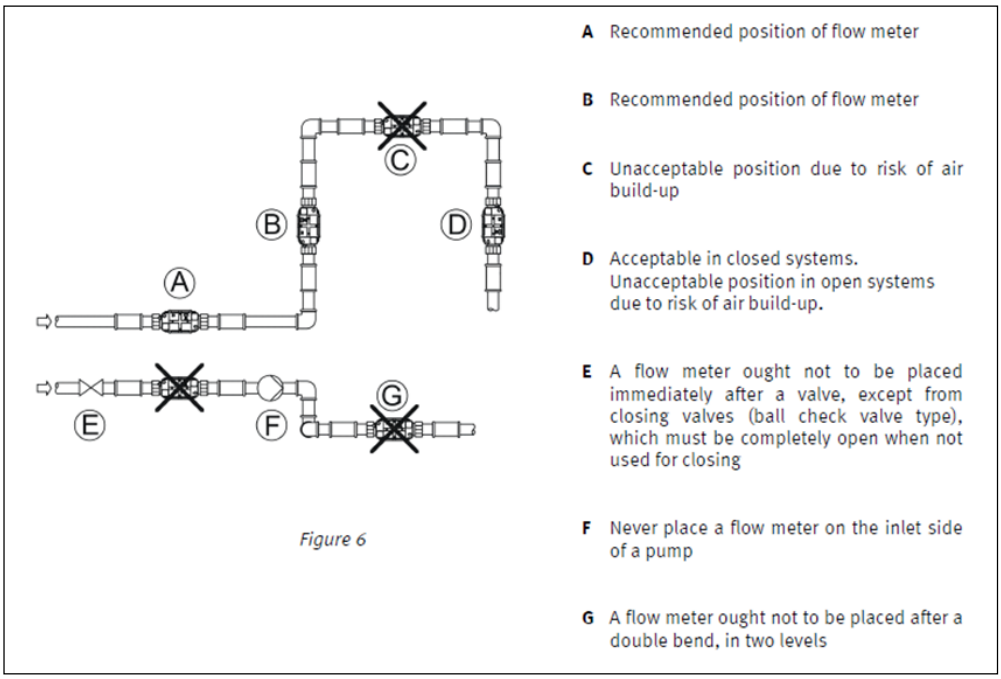


Figure 71: Example of recommended installation positions of a flow meter [30]

6.2 Calculation of energy consumption

District heating energy is calculated according to the flow rate and temperature difference between flow and return district heating pipes. The specific heat capacity and density of the water depends on the temperature.

$$Q = c_p \int_{t_0}^{t_1} q_m \ \Delta T \ dt \qquad (1)$$

Where:

Q = Heat energy consumption

c_p = Specific heat capacity of district heating water

q_m = District heating mass flow

ΔT = District heating water temperature difference

t_0 = Time, start

t_1 = Time, end

The accuracy of the calculation depends mainly on the accuracy of the measurement devices. Another cause of error is the integration of flow rate over time span. Flow information will be transmitted in pulse mode and the pulse time or amount of water flow per pulse has influence on the actual accuracy of the calculation. The longer the time span is or the bigger the water pulse is the bigger is the error of calculation, because temperatures will vary all the time.

The following picture presents a typical accuracy of one type of district heating energy meter, which consists of flow meter, temperature sensors and a calculator. The picture also shows the acceptable error of an energy meter according the standard EN 1434 [31].

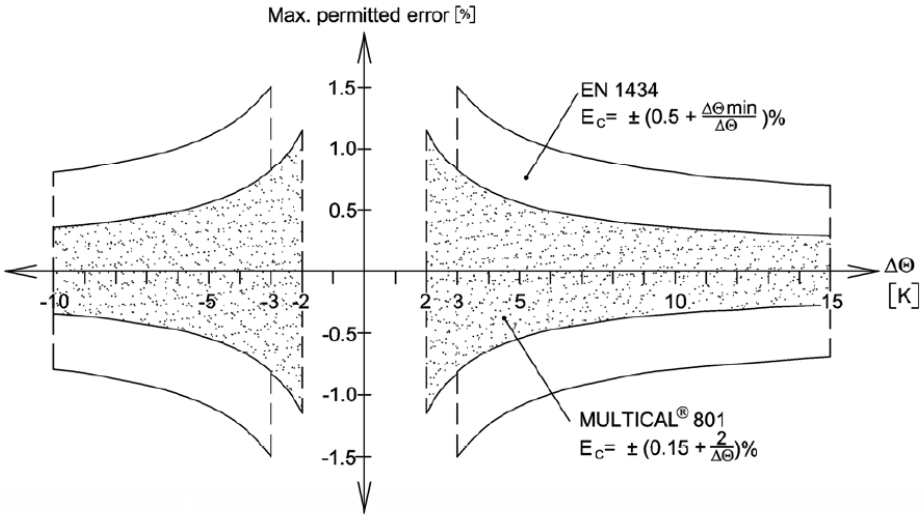


Figure 1

MULTICAL® 801 typical accuracy compared to EN 1434.

Figure 72: Typical accuracy of Kamstrup Multical 801 [31]

In the picture the maximum permitted error according the standard EN1434 is less than +/- 1,5 %. And with normal flow rates the error should be less than +/- 1,0 %.

6.3 Maintenance of heat metering equipment

Control and maintenance of heat meters should aim to ensure the accuracy of metering equipment during the whole life span of measurement equipment. The acceptable accuracy limits will be set according to legal requirements and terms of heat delivery contracts. This is important during the whole operating lifetime of the heat meter. It will be the benefit of the customer as well as district heating company.

Traditionally district heating companies have not used remote reading for heat meter maintenance. The only usage of measurements has been analyzing the billing data and monthly average cooling of district heating water.

It is not reasonable to install apartment level heat meters to measure the consumption of district heating. Building level metering is suitable for the district heating system. It is a different matter to install apartment level meters in order to deliver total district heating consumption to apartments. This work should be done by the building owner or the housing company. There can be services available for this purpose and the district heating company can also have those type of services which are independent from the normal district heating business.

6.4 Measurement policy

The installation of the heat energy meters is a part of the overall quality and operation policy of the company. Several different types of boundary conditions and other issues must be considered during the planning and management of a measurement policy and system. The conditions and issues that must be considered are as follows:

- Reasons for measurement: billing data, energy consumption information, data for production, heat losses, energy saving, services etc.
- At an early stage of implementing the measurement system, it is important to decide for which kind of customers the heat meters will be installed, or from which customer group (one family houses, apartment buildings, offices, hotels, industry etc.) to begin the work (final goal should be installation of measurement to all customers).
- What should be done with the measurement results and collected data (energy, peak demands, flow rates etc.)?

Organisational questions of the district heating company from a measurement point of view:

- What kind of organisation, and what are the skills and training of personnel
- What to do yourself and when to use a contractor
- Management skills
- Need for training
- Amount of different level personnel

Several technical issues like:

- District heating network and its limitations (where to install, connection scheme of the main network etc.)
- Water quality, due to different requirements of different types of heat meters (conductivity, purity etc.)
- Connection scheme of the consumers (substations, heat exchangers, direct connections etc.)
- Temperature and pressure levels (some water meters are for 90 C° temperature and some for 100 C° or 120 C° etc.)

The main measurements in a district heating system are presented in the following figure.

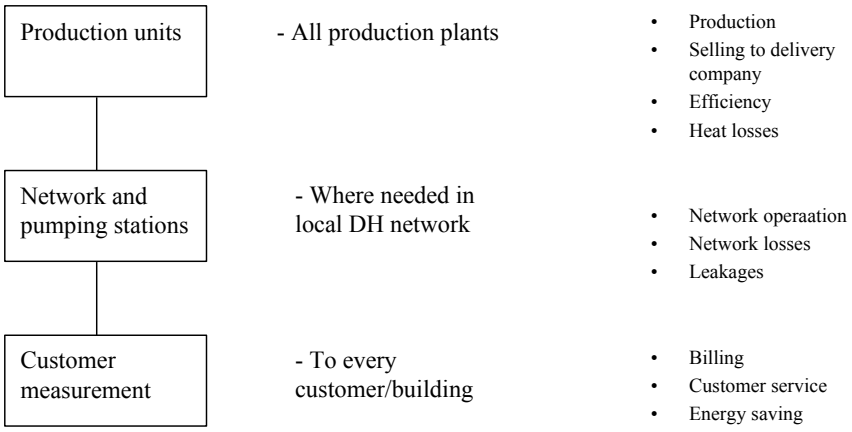


Figure 73: District heating main measurement

6.5 Definition of a customer

The definition of a customer is a key question in heat metering. The main concept should be that every customer is equipped with a heat meter. There are questions like:

- Who is the customer
  - Building in a technical point of view
  - Contract partner (legal customer); In Finland the building owner, for example the building company is always the contract partner and a customer.
- In Finland an apartment building is the customer, never the inhabitant

How to organise the use of an apartment level heat energy metering (for the billing of district heating)? In Russia, the district heating company must charge apartment specifically if the customer installs the gauges. New norm should be so that the district heating company invoices only the housing company (or building association) and that the bill is divided by the housing company.

In Finland, real estate is always the customer (the housing company is a functional solution for that problem). In Finland, an apartment is never a customer; on the contrary, the whole real estate is the customer. The housing company can use apartment-specific measurements as the basis of cost distribution.

The customer in Russia

- Usually a contract between the resident / the owner of the apartment
- In old apartments the billing is based on the consumption according to the norm (theoretical consumption)
- Since 1.1.2007 the new “law of housing company”: the heat contract is or can be made with the housing company.

It is recommended that the real estate is always the customer (the housing company is a functional solution for that problem). It is recommended that an apartment is never a customer, but on the contrary, the whole real estate is. The housing company can use apartment-specific measurements as the basis of cost distribution.

6.6 Apartment level heat metering

In Finland

- Customer is always a building or a company
- District heating companies do not invoice in apartment level

Benefits of apartment level measurement systems are not so evident than sometimes some international organisations claim. In Finland the consumption of buildings in the 90’s (KWh/m^3, year) was lower than for example in Germany, which means that good results in energy savings can be achieved by other means better than using apartment level energy metering.

7 District Heating Quality System

Having high quality norms and recommendations as well as high quality components does not guarantee high quality, reliability and a long lasting system. First, there is a need for a new design philosophy and for the optimisation of heat production. After that, there is a huge need for quality control systems in the Russian district heating. Particularly in the district heating network, this kind of system is needed.

The main features of the district heating network quality management system:

- Approval of the system and quality tests of approved components (pipes, joints, valves and other equipment)
- Certification for installing personnel (welding, joints and insulating work etc.)

The main principles of district heating quality management system are presented in the following figure.

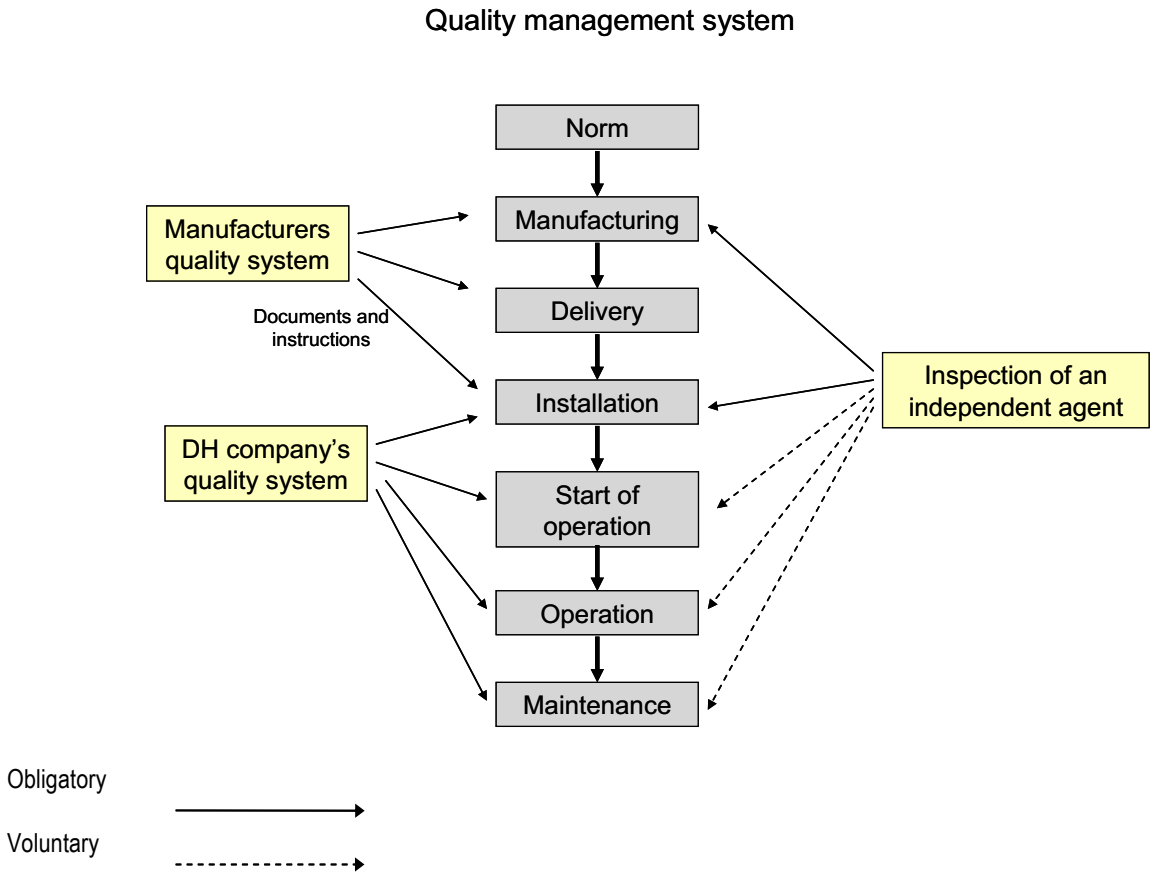


Figure 74: District heating Quality management system

There will be a need for a quality management system in the norm or in other higher levels. Some parts of the quality system can be organized by the manufacturers or the district heating company's own quality management system. In some parts, there will be a need for independent quality inspections to be made by authorized organizations (specialists or some association etc.) to give official and independent status (officially approved system). It is important to have some inspections and tests during the normal operations

so that the real quality level can be guaranteed. It seems that quite many of the pipe elements and joint systems assembled in the district heating network are remarkably lower in quality than those in Finland.

In most cases, the welding work of the district heating pipes is well controlled and well done because that part of the work is controlled by the norms of pressure vessels, due to the high temperature and high pressure of the district heating water. Nevertheless, it is precisely as important to have high quality pipe joints and joint insulations because most of leakages of the district heating pipes are a result of outside water that has come through poor joints of the plastic covered pipes. This will be the situation in Russia as well, when the system design is renovated. It must be kept in mind that polyurethane does not resist against water when the temperature rises from normal room temperatures. Corrosion spreads quickly in a pipe covered by wet polyurethane.

There are recommendations given by the Finnish Energy industries concerning quality management and quality tests of district heating pipes and joints in Finland. Most of the quality control tests are made according to international standards. All pipes in Finland have to be marked as "*LT*" mark, which shows that the quality system is approved and that quality tests have been made.

The main result of the new quality control system is that it will guarantee the following:

- material and equipment are as good as ordered or purchased or said in norms
- installation and manufacturing has been made with sufficient quality
- it is possible to operate equipment and the system as planned
- it is possible to achieve planned operational lifetimes of equipment and systems (pipes, heat exchangers, valves etc.)

While examining the network, the Finnish and Russian norms are compared to distinguish whether there are differences in regulations and requirements, i.e. which is stricter, more accurate or what kind of differences are there between the requirements. Conventionally, Russian norms are strict and harsh by their requirements. The next question is why are the implementation and results worse in quality and functionality when following the stricter Russian norms. The main solution for this problem is a new quality control system that really works and guarantees the quality of equipment and installation work (presented in chapter 3).

Technical questions can be divided, for example, into the following:

- the norms and guidelines of planning
- sizing and selection of components and equipment
- materials (pipe material, insulation material, protective coating, other materials like canals and chambers)
- installation work, supervision of installation, methods and materials used, equipment etc.
- operation and maintenance

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