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DISTRICT HEATING SYSTEMS IN FINLAND AND RUSSIA

Bachelor Thesis
Building Services

March 2011

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Date of the bachelor's thesis

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Degree programme and option
Building services

Name of the bachelor's thesis
District heating systems in Finland and Russia

Abstract

The subject of this thesis is the examination of district heating (DH) systems in Finland and Russia. The main aim is to study Finnish experience in this field and to consider the possibility of applying Finnish systems in Russian conditions.

The thesis presents the state of DH market in northern countries, shows the benefits of using DH systems, and describes various schemes of connecting DH network to buildings, as well as their advantages and disadvantages. The present situation in the sphere of DH in Finland and in Russia is also considered. Having considered the current situation with DH systems in Russia and the successes achieved in the field of heat supply in Finland, one may draw a conclusion that Russian DH networks need urgent renovation, taking into account and using Finnish experience of operating DH systems.

Such DH system renovation for the existing buildings in current economic conditions is very complex and can't be solved in one stage and in a short period of time. However, there are some tasks which can and have to be done now. Building norms and regulations should be revised taking into consideration Finnish experience in operating two-pipe DH networks with independent connection to the buildings.

Thus, for renovation of Russian DH systems new norms of designing and maintaining should be worked out. It is also necessary to establish more strict and modern norms of energy efficiency taking into account wide Finnish experience in this field.

Subject headings, (keywords)
District heating system, central substation, individual substation, CHP plants, schemes of DH connection, renovation of DH system.

Pages	Language	URN
39	English	

Remarks, notes on appendices

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Employer of the bachelor's thesis

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APPENDICES

1 INTRODUCTION

District heating (DH) is a widely used form of heating in densely-built areas of Northern Europe, the United States of America, and most of Russia. That is why the supply of heating energy must be reliable, safe, efficient, and have a very high degree of security of conveying. In order to meet all these requirements the system must be properly designed and run.

At present time the total length of district heating network in Russia is quite large. Most of networks need urgent rehabilitation according to modern standards. Upgrading district heating networks in densely-built areas would reduce total consumption of heating energy.

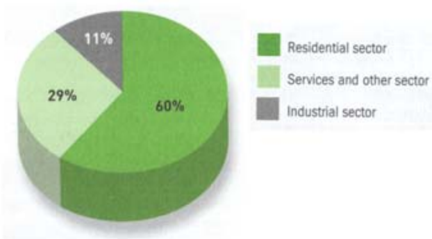
In order to modernize Russian DH systems it is necessary to study and analyze at first the situation with DH in Russia, and then the foreign experience in this field. Finland is the country bordering Russia and having quite similar weather conditions with the northern regions of Russia. And besides, Finnish DH system is considered to be energy efficient, safe, and customer oriented. That is why in this thesis work the structure and principle of operation of Finnish DH systems are considered. The aim of this work is to examine Finnish experience in the field of DH systems and to consider the possibilities of applying Finnish methods in Russian conditions.

2 GENERAL

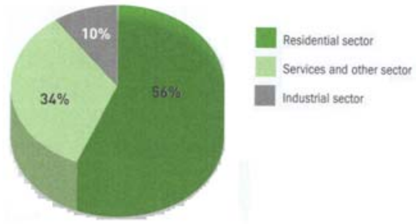
2.1 District heating market

District heating market in Northern Europe is growing rapidly every year, and now accounts for more than half of all heating in different types of buildings. For example, in Finland estimated number of residents heated by district heating is about 2.57 million inhabitants, in Sweden - about 1.85 million households heated in residential houses, 182710 in single family houses, and 91.0 million square meters in other premises, and in Denmark – 1.54 million households which is about 61% /1, pp. 113, 358, 81/. The percentage of District heat delivery in different sectors is shown in picture 1.

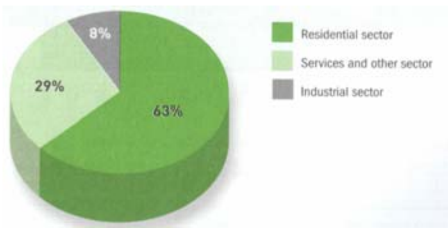
In Russia district heating market is already developed. About 91% of all buildings in large cities and about 60% in small towns are connected to district heating network /1, p. 74/. More detailed information about the number of consumers, kinds of fuel used for heat energy production in DH sector, and amounts of CO_2 emission from district heat production are given in Appendix 1.



Sweden



Finland

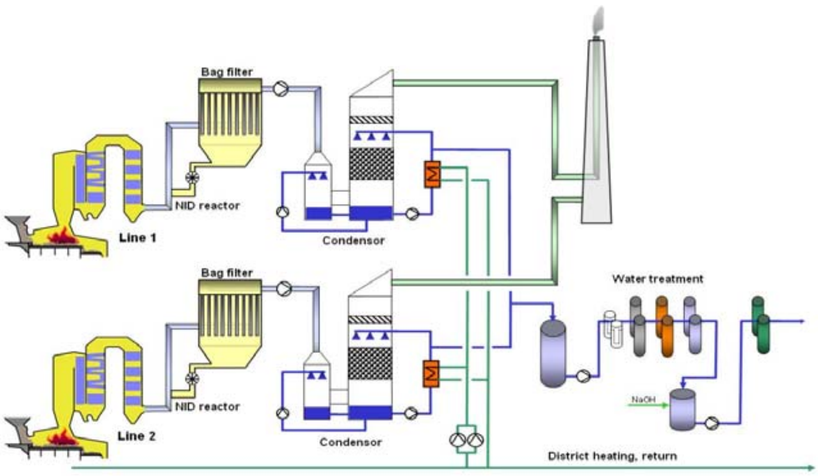


Denmark

Picture 1. District heat delivery by sectors /1, pp. 359, 114, 81/.

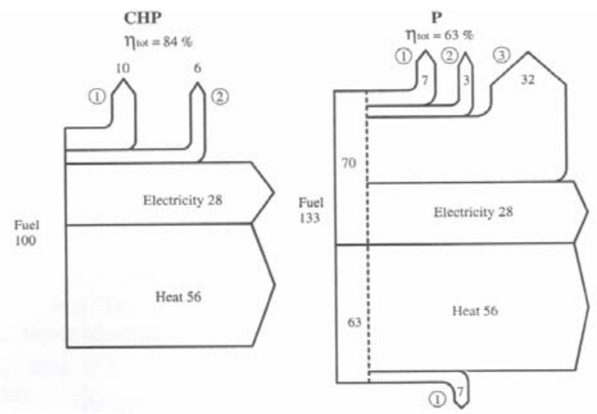
2.2 District heating influence on the environment

Nowadays district heating networks is an essential part of urban life. DH systems have several advantages as compared to individual boilers. Centralized energy production contributes much to the protection of the environment, significantly improving it by reducing harmful emissions. When energy is produced in centralized power plants with using highly efficient equipment for flue gas cleaning, as it is shown in picture 2, there is the possibility to control the quality of flue gases purification, and the level of NO_x emission in accordance with the requirements of the environmental license. In all centralized power plants there is the practice to install heat recuperates which use flue gases heat.



Picture 2. Principle scheme of cleaning of flue gas /3, p. 14/.

At present, it is very common to produce electricity and heat energy at one power plant. Such facilities are called combined heat and power production plants (CHP plants). They are even more environmentally friendly because combined energy production significantly increases CHP plants efficiency and allows saving fuel consumption and thus reduces CO_2 emissions to the atmosphere. The schemes presented in picture 3 illustrate the benefits of combined heat and power production.



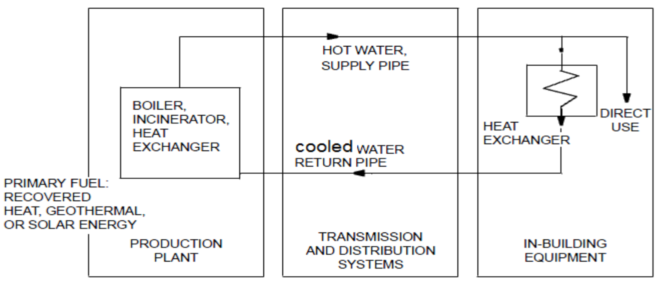
Picture 3. Benefits of combined heat and power production /4, p. 12/.

In conclusion, taking into account the calculations performed by Danish energy company TVIS, it should be noted that “the volume of CO_2 emitted by an oil heated house equates to the volume of CO_2 emitted by 2.5 houses heated with natural gas or 4 houses heated with district heating” /5, p. 2/.

2.3 District heating system structure

District heating system is a thermal energy network that supplies hot water by means of insulated pipes to serve commercial, residential, and industrial energy needs for space heating, air conditioning and domestic hot water (DHW). Hot water serves as the main heat transfer media in the systems of centralized heat supply. District heating water is heated in large centralized plants and transported through pipe networks which are located in the ground or above the ground, depending on local conditions.

DH networks are mainly made two-piped. DH system network consists of two kinds of pipelines: a pipeline for supplying hot water from heat source to the system of heat consumption and a return pipeline. The latter serves for returning water cooled in heat consumption system back to the heat source for reheating. Supply and return pipelines together with the corresponding pipelines of heat sources and consumption systems form closed water circuit. This water circulation is supported by network pumps installed at the heat sources. When the distances of water transportation are long, intermediate boosting stations are installed. In picture 4 there is the scheme of DH system.



Picture 4. Main components of District Heating System /6, p. 11.1/.

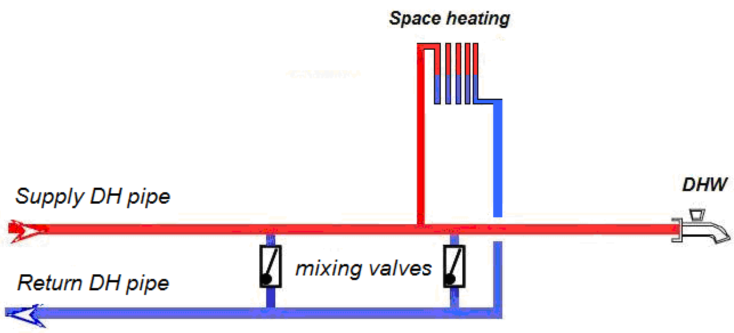
There are two schemes of district heating network connection to buildings: direct and indirect. They differ from each other by the ways the heat can be transferred from district heating network to the internal space heating system and to the domestic hot water distribution network: directly from district heating network or indirectly by heat exchangers. They also are called depended and independent, respectively. When the independent scheme of DH connection is used for DHW system, it is called a closed scheme and when it is applied for space heating system, the term indirect system is used. Dependent scheme of DH connection for DHW system is called an open scheme, and when used for space heating it is called a direct scheme.

2.4 Open and direct schemes of district heating network connection

When the system is open, water is the same both in the DHW system and in the radiator network. The principle of open DH connection see in picture 5. Open schemes of DH connection have a lot of disadvantages.

2.4.1 Disadvantages of open scheme of district heating connection

The main disadvantages of open DH schemes are the following: it is dangerous for inhabitants because the DH water is chemically treated; the temperature of DH water is high, usually it is from +70 ^{0}C to +135 ^{0}C. The temperature of DH water depends on the design parameters of the whole DH system and the parameters of the boiler plant. It is very difficult to control the temperature in DHW network. When open scheme of connection is used, there is a risk of getting too hot water or even steam from taps because the pressure and temperature in DH network is rather high. The high pressure can also be a reason of leakages and high flow rate in DHW network /4, p.14/.



Picture 5. The principle of open District Heating connection /7, p. 17/.

In the open scheme of DH connection there is a huge amount of makeup water for compensation of DHW needs. This water requires spending extra money for treatment of extra DH water. In open DH systems 20-30% more makeup water is required for DHW needs than in closed system /4, p. 27/. In case the water treatment does not satisfy the requirements of DH water preparation, there will be numerous problems such as corrosion of DH pipelines, space heating network, and DHW pipes and also corrosion of heat producing boilers and other equipment of DH systems. All these disadvantages reduce service time of the whole DH system extremely.

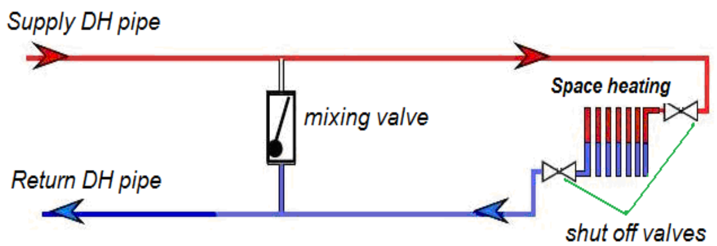
2.4.2 Advantages of open scheme of district heating connection

This scheme requires neither heat exchangers nor circulation pumps. Thus the advantage of the open scheme of DH connection is that it does not need a lot of money investments for equipment preparing DHW. This scheme requires neither heat exchangers nor circulation pumps.

Direct connection for space heating system means that district heating water circulates in the radiator network, too. The principle of this type of connection is illustrated in picture 6. This scheme of DH connection also has some disadvantages and advantages.

2.4.3 Disadvantages of direct scheme of district heating connection

At first, in using direct scheme of DH connecting there is no necessary and exact water temperature control in DH and in space heating networks according to outside conditions, the so called weather compensation. It means that the temperature in the radiator network can be much higher than it is necessary for compensating heat losses when outside air temperature is not so low. The high temperature in the return DH network can cause extra heat losses. The high return temperature of DH water is one of the reasons of uncomfortable conditions inside the buildings.



Picture 6. The principle of direct District Heating connection /7, p. 17/.

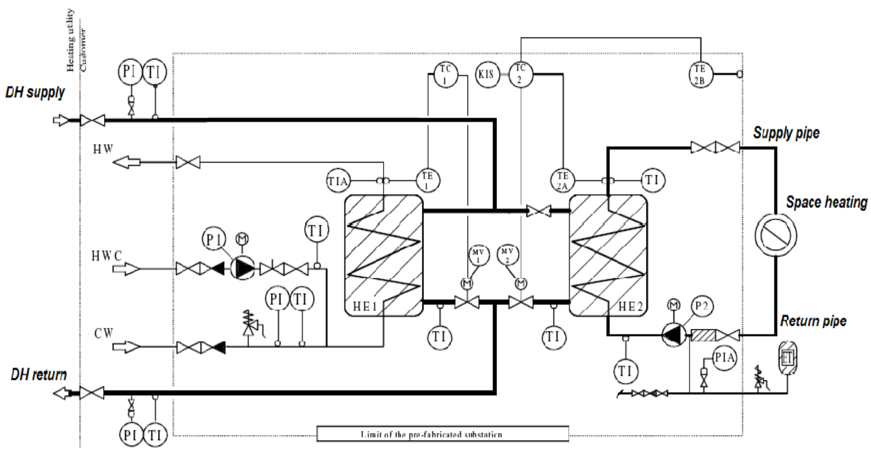
In a DH network a huge amount of water is transported to many different customers and in case of leakage in some internal networks there is always a danger that all DH network water, circulating in the same pipe system, will leak and the scope of damage can be great.

2.4.4 Advantages of direct scheme of district heating connection

The main advantage of direct DH connection is that it does not require large investments in automation system of every building because DH water parameters are regulated for the groups of the buildings. The system with direct DH connection does not require the installation of circulation pumps on the space heating side. When the building is not tall, it is not necessary to install the pumps in the building because the DH network pressure is enough to provide water circulation in the internal networks.

2.5 Closed and indirect schemes of district heating network connection

In the closed system DHW is produced, that is heated by heat exchangers. When indirect connection is used for space heating systems, the DH and the radiator networks are separated from each other by means of heat exchangers. The scheme of closed and indirect DH connection is given in picture 7. In comparison with open and direct schemes of connection to DH network, closed and indirect schemes have more advantages than disadvantages.



Picture 7. The principle of the closed and indirect District Heating connection /4, p. 26/.

2.5.1 Advantages of closed and indirect schemes of district heating network connection

First of all, it should be noted that closed and indirect scheme is the safest scheme of connecting consumers to DH network. The main advantages of indirect connection are the following: uniform heating of all the flats in the building; leakage in either the district heating pipeline or the radiator network is only limited to that system and doesn't drain the other one; automatic control during the whole heating season takes into account the weather compensation and the possibility of saving energy during the transition season from 20 to 40% of total consumption and also energy saving due to temperature reducing; DHW is heated in heat exchanges and that is why this system needs minimal extra makeup water for replacement of DH water resulting in low oxygen levels and significant reduction of corrosion of DH networks and other DH equipment; safety factor for example, the pressure and the temperature are lower in the building; this type of system makes each customer more independent as far as heat energy is concerned because consumers can get their own control of all necessary parameters for creating individual thermal comfort, and have energy costs saving /4, pp. 26, 33/.

2.5.2 Disadvantages of closed and indirect schemes of district heating network connection

There are two main disadvantages of closed and indirect schemes of DH connection. This system requires more technological equipment, such as heat exchangers and pumps and therefore it is more expensive. In case of high pressure it is necessary to install expansion system at the secondary side for preventing destroys of internal networks.

3 DISTRICT HEATING SYSTEMS IN RUSSIA

3.1 The importance of district heating in Russia

Russia is a country with severe climate conditions. Cold season in the most of regions lasts more than 200 days at average outdoor air temperature below -5^0C. In the northern climatic zone, which covers almost half of Russia's territory, heating period characteristics are even more severe. For example, the heating period for town Chita is 238 days at average outdoor temperature -12.4^0C, and for Verkhojansk town it is 272 days at average outdoor air temperature -25.2^0C. Therefore, well designed, properly operated, and having high standards of performance DH system is extremely important in Russian climatic conditions. Climatic map of Russia is shown in Appendix 2. About 90% of all dwelling buildings in densely-populated areas of Russia are connected to district heating systems. The total length of DH network in Russia is about 275. 000 kilometers /8, p. 35/.

It is not a simple matter to maintain optimum comfortable indoor climate parameters in such conditions. More than 30% of all the fuel extracted in the country, which makes about 600 million tons of standard fuel, is to be burnt to provide buildings with heat energy /9, p. 6/. For the most efficient use of fuel and in order to provide the consumers with heat energy safely, it is advisable to use DH systems in densely-built regions.

3.2 Present situation of district heating systems

Nowadays in Russian cities there are a lot of consumers not satisfied with centralized DH system and who would prefer not to connect their buildings to district heating network, but to use autonomous heating systems. The main reasons of that are the following: the system does not meet the customer needs, the system is not energy efficient, and using existing parameters makes the operation of such a system dangerous.

At present time power-generating sector in Russia is in a difficult situation. Equipment, methods of production, transportation and regulation of heat energy have become out of date. Steady growth of the volumes of energy consumption revealed the problem of generating capacities deficit. At present in operation in Russia there are 485 CHP plants, about 6500 boiler-houses with the capacity more than 24 MW, more than 100,000 small boiler-houses and about 600,000 autonomous individual heat generators. About 35% of heat energy from all DH system heat loads is produced at CHP plants. Total heat energy production in Russia is 2400 million MW/365 days. 1265 million MW are produced for the needs of residential consumers, 1130 million MW are produced for industrial enterprises. 400 millions tons of standard fuel are spent a year to produce this energy amount /8, p. 32/. According to the data of Russian Federation Ministry of Energy the level of total DH systems wear is 59%. Heat generating equipment wear is 68%, DH networks wear is 59%. It is estimate that at present time 15% of DH networks demand urgent replacement. In order to make the condition of

DH water transportation system reliable, it is necessary to completely repair or to build anew 150,000 km of DH networks /8, p. 39/. According to the data presented by the head of the Ministry of Energy Mr. Basargin in 2009 there were 1520 accidents at the DH networks serving residential sector. The Minister also marked that during the similar period in 2008 there were 1380 accidents. Thus, one can draw a conclusion that DH systems are in the state of emergency. See picture 8.

Picture 8. Example of some district heating pipelines condition. /8, p. 35/.

3.3 Standards of Russian district heating system

Standards and specifications of the existing in Russia DH system were developed in 1950 s. They have not actually changed since that time. At the time of creation it was a quite modern, economically efficient DH system which allowed rapid transition from individual heat sources to centralized heat supply. The main purpose of these standards was to build fast a system which should not be material-intensive. Also it was not so important to take into account prices for oil, gas, coal, and other energy sources, because there has not been a lack of fuel in Russia.

For example, the standards for optimization of combined heat and electrical energy production these standards were accepted in 1970s and are still valid. According to them it is permitted to build CHP plants with minimal heat capacity of 300-500 MW. Construction of the same CHP plants in Western Europe is considered economically profitable with heat capacity of 30-40 MW /4, p. 16/.

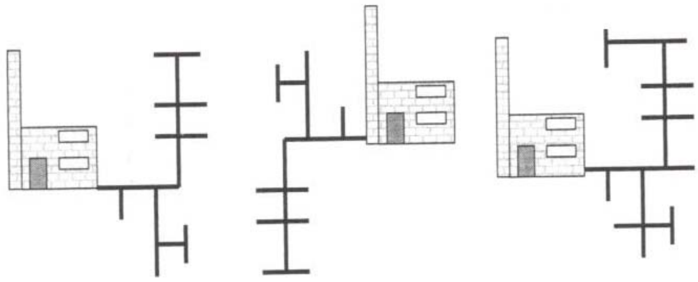
Some Russian standards of designing DH network are not energy efficient and even can be dangerous for consumers. Until now according to Russian standards of designing DH systems it is allowed to connect buildings using open scheme of connection to DH network. It should be noted that dependent scheme of DH connection is recommended by Russian norms of designing DH systems. As mentioned earlier they are quite dangerous and not efficient types of DH connection.

According to Russian standards the temperature in DHW network should not be less than $+60^0$C. So, when open and direct schemes of DH connection are used, during transition season water in DH systems is supplied at the temperature about $+60^0$C. This situation is very common to St. Petersburg. But according to calculations of heat losses, taking into account weather compensation, it is not necessary to supply water to radiator network with such a temperature. This is the reason of quite high temperature in radiator network and uncomfortable conditions inside buildings due to overheated internal spaces. Thus, water in a radiator network does not get cold enough and returns to a boiler plant quite hot. The high temperature of return DH water is the result of bigger heat losses in return DH pipelines.

3.4 Principle district heating systems in Russia

Russian DH system scheme consists of the following main parts: source of heat, distribution network, central substation, and individual substation. The principle of operation of such a system is the following: heated water leaves the source of heat at the temperature $+135^0$C. Then it is delivered to the central substation. There it is cooled to $+95^0$C, for some groups of buildings to $+115^0$C. The reduction of water temperature is performed by admixing cooled water from the return pipeline of the DH system. When DH water temperature is changed, it is delivered to the individual substation. Distribution of DH water to DHW system, to DH system, and to heat supply of air handling units (AHU) occurs in the individual substation. The principle of operation of individual substation see in chapter 3, paragraph 3.6.

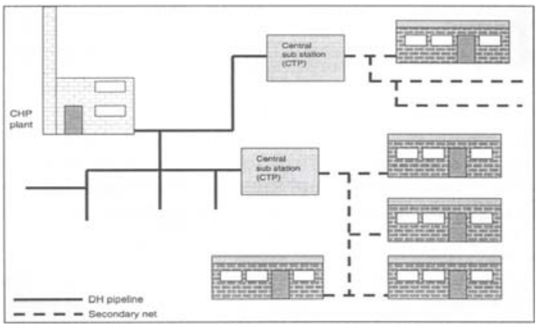
It is characteristic for Russian DH systems to use only one source of heat energy production for the entire DH system without providing additional boiler-houses for reservation and compensation of the loads at the time of the largest heat energy consumption. This system is described in picture 9.



Picture 9. Russian District Heating system with one source of heat /4, p. 17/.

3.5 Central substation

A central DH substation is one of the parts of a central heat supply system used for different types of buildings. It is an intermediate in the production, delivery, and consumption systems. Picture 10 illustrates typical for Russia DH system using central substations. The main aim is to prepare, distribute, and deliver heat and domestic hot water to the group of buildings. One central substation serves two or more buildings of the same intended group.



Picture 10. Typical scheme with central substation /4, p. 28/.

According to Russian norms and standards of designing district heating systems and central substations, in every central substation the installation of fittings, checking instruments, devices of control and automation is provided /10, p. 35/. The system of central substation automation is to carry out the control of the following parameters: regulation of supply DH water temperature, measuring of heat flows, measuring of DH water consumption, protection of the internal systems of the building against accidental increase of DH water parameters such as temperature and pressure, control of filling and makeup of DH system, heat accumulation, heating of water for DHW system. In accordance with Building norms and regulations of designing district heating systems in Russia it is permitted to carry out all or only part of above-mentioned measures of regulating parameters in a central substation /10, p. 35/.

Utilization of systems distributing heat energy by means of central substations is a less efficient method as compared with applying individual substations installed in every building. Systems with central substations have more heat energy losses at all DH system levels after central substation resulting in heat losses by consumers due to the overheating of the building during transition season /4, p. 29/.

Large heat energy losses arise because of the low quality of the automation system which does not permit to control individual heat energy consumption in the building. Due to the imperfection of the norms of designing DH systems it is also not possible to control the parameters of the entire DH system more precisely. In practice, it is quite often that the system of automation and control at the central substation is not used. That is one of the reasons of very low cooling of return DH water in the cold season. Design temperature of return DH water is +60 - +70^{0}C, but in real conditions the temperature difference of return and supply DH water is only +20 - +30^{0}C. Thus, the low temperature of return DH water is the result of the DH network low heat carrying capacity. Low heat carrying capacity of the DH network is the cause of additional expenses for extra pumping and extra heat losses in DH network. In comparison with the corresponding indices in Finland, the expenditure of electric energy for extra pumping of DH water in Russia is two times more. For example, in Russia electric energy expenditure is about 20 - 25 kWh/MWh district heat from production. In Finland this index is about 10 kWh/MWh /4, p. 30/.

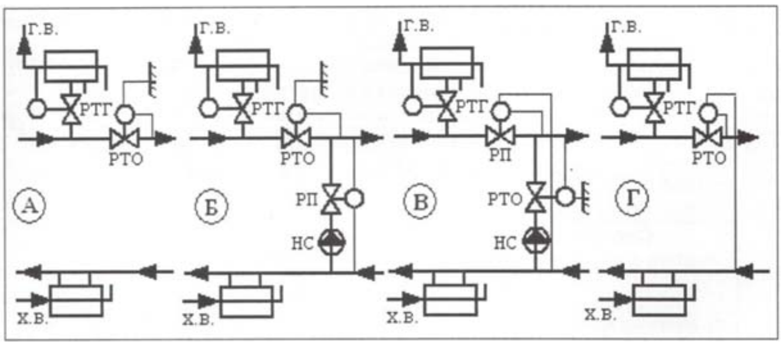
It is also should be noted that in a central substation the control of DH water parameters will never be carried out as exactly as it can be performed in an individual substation. Low quality control of DH water parameters after central substation is explained by too long pipelines from the control point to the consumer, and also by the difficulties of balancing the internal space heating system. The pipelines of quite great length result in the increase of heat losses and in the reduction of return DH water temperature due to the necessity of overheating the supply DH water in order to provide enough heat energy in every flat.

The main disadvantage of heat delivery group regulation at the central substation is that every scheme is worked out for buildings with definite purpose, but regulation of heat flows for groups of buildings with different thermal conditions is impossible by using only one scheme. For example, when one scheme of heat flows regulation is used for a group of consumers consisting of residential and administration buildings, heat energy supply is inefficient during transitional heating season with the open scheme of DH system connection. In order to provide the required by the norms water temperature in DHW system, the temperature of water in DH network is maintained at a higher level than it is necessary for a heating system with small heat losses of the building. In this case, the main aim of the central substation automation system is to prevent the overheating of the buildings. Thus, larger amount of heat energy is produced than it is required.

In winter season, when DH water temperature in the space heating system is to be higher than the temperature of water for DHW system needs, there occurs under delivery of heat energy to the consumers for space heating. For example, DH water temperature can be lower than it is required according to the heating schedule because of the damage at the heat source, fuel shortage or outdoor temperature fall below the design temperature for heating system. In this situation, the purpose of the central substation automation system is to prevent misalignment of DH network. When the DH water temperature in the distribution network falls, automation system in the central substation responds and opens the valves regulating the DH water temperature. As a result, the uniform heat supply is not performed. This misbalance is lower on the head sections and higher on the end sections of the DH network /4, pp. 30-31/.

The internal space heating system is connected to the central substation by means of correction mixing pumps in case of the dependent scheme of connection with a mixing valve in an individual substation of each building. In case of the closed scheme of connection it is connected by means of heat exchangers. Domestic hot water systems are connected to the central substation by means of heat exchangers in case of the closed schemes of connection and for the open scheme of connection a mixing valve is used. When buildings are connected to the central substation by means of the closed DH scheme, there is a four-pipe DH system installed between the central substation and the building. Such a scheme includes supply and return DH pipes for DHW and space heating systems. When this scheme is used, investments increase considerably. There is a large increase in heat energy losses and also much more electricity is used for transporting water for DHW needs. It should be noted, that the service life of the pipelines delivering water for DHW system is significantly shorter, because delivered water is not treated and contains large amount of oxygen /4, p. 27/. In the picture 12 different schemes for connecting DHW and space heating systems with using a central substation are shown.

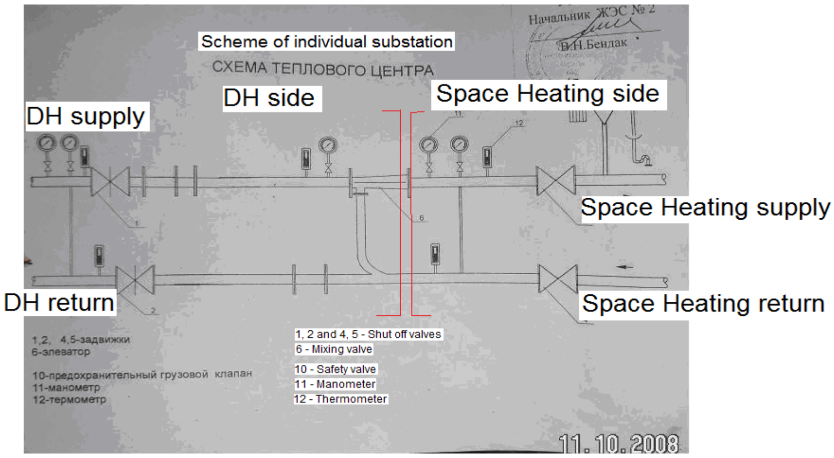
In the picture 11 the following marks are used: In the picture: **РТГ** – hot water temperature regulator; **РТО** – heating system heat-carrying agent temperature regulator; **РП** – heat-carrying agent consumption regulator; **НС** – mixing pump; **ХВ** – cold water from city water pipe; **ГВ** – second grade heating hot water



Picture 11. Typical Russian solution with connection of space heating and DHW to district heating network /4, p. 30/.

3.6 Individual substation

According to Russian standards and rules of designing DH systems, it is necessary to install an individual substation in every building irrespective of the availability of the central substation. In individual substation only those functions are provided which are necessary for connecting the building to the DH network. Usually the following equipment are installed in an individual substation: a mixing valve, filters for supply and return DH pipes, accumulators of heat energy, thermal insulation, different fittings, pumps when it is necessary to rise pressure in a supply pipeline of a space heating system, distribution and return manifolds as a rule, it is a pipeline of a larger diameter with the connection of the space heating system to it. In the picture 12 a typical scheme of an individual substation with a mixing valve installed in a residential building is shown.

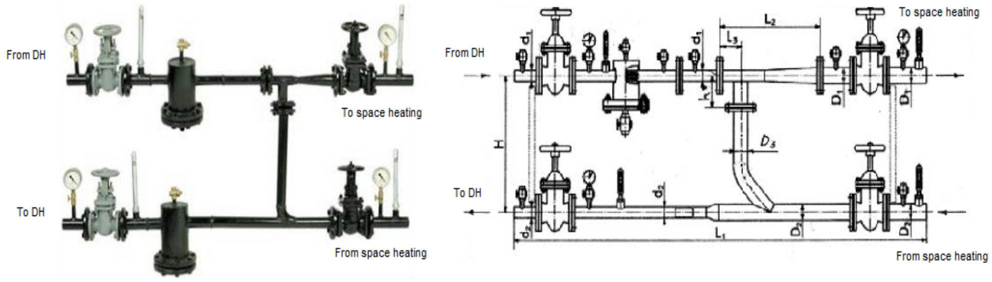


Picture 12. Scheme of individual substation /11/.

The main aim of the individual substation is distributing DH water for space heating system and DHW. For regulating DH water temperature a mixing valve is usually used. The principle of mixing valve operation see in chapter 3, paragraph 3.7. In accordance with the norms of designing individual substations, space heating systems, ventilation and air conditioning should be connected to two-pipe DH system by dependent scheme of DH connection. It is allowed to connect these systems to the DH network by means of heat exchangers, with the usage of reserve heat exchangers. For every system two heat exchangers are installed, on condition that each heat exchanger is rated for 75% capacity from the total heating load /10, p. 7/. Connecting the internal systems of the building by the independent scheme of DH connection makes the system much more expensive, and that is why such connection scheme is found very seldom.

3.7 Principle of mixing valve operation

A mixing valve is a widely used means for regulating the temperature of space heating water in internal networks of buildings in Russia. It is used in DH systems with the following parameters of water: maximum temperature is $+150^0$C, maximum pressure is 1.6 MPa. A mixing valve given in picture 13 is installed in individual substations in every building. Its main purpose is to reduce the space heating water temperature in radiator and DHW networks. During the transition season it reduces the temperature of water in a radiator network, and in winter it reduces the temperature of water for DHW needs according to the allowable range of temperatures for those systems.



Picture 13. Mixing valve /11/.

The principle of mixing valve operation is based on mixing DH water from return pipeline of a radiator network with supplied water. DH water from supply pipeline is delivered to a conic removable nozzle where the water velocity sharply increases. As a result, the water jet coming out of the nozzle to a mixing chamber draws cooled water from a space heating return pipeline of a radiator network into the inner cavity of a mixing valve. Thus, in a mixing valve occurs mixing and reducing the temperature of the water supplied to the internal networks. Mixing valve operation depends much on correct choice of sizes and diameters of water delivery pipes leading from supply pipeline of DH system and return pipeline of internal space heating system and also on nozzle diameter choice.

Mixing valves have gained wide acceptance in Russia because they don't require large financial expenditures during their operational life; they don't need installing automatic systems in contrast to systems using heat exchangers; they don't require constant inspection by service personnel.

4. DISTRICT HEATING SYSTEMS IN FINLAND

4.1 The importance of district heating systems in Finland

Finland is located in the northern part of Europe. Climatic conditions there are such that the weather can change quite fast especially in winter time. The average January temperature for the period 1971 - 2004 was -4^{0}C in the southern part of Finland, and about -14^{0}C in the northern one. Heating degree days in Finland are counted between 3,900 and 6,400 /1, p. 112/. Thus, heat supply system in Finland should be reliable and energy efficient. The most common form of heating buildings is DH system. It has been in operation in that country from the early 1950s /12/. More than half of Finnish inhabitants live in the houses heated by DH system.

4.2 District heating system development

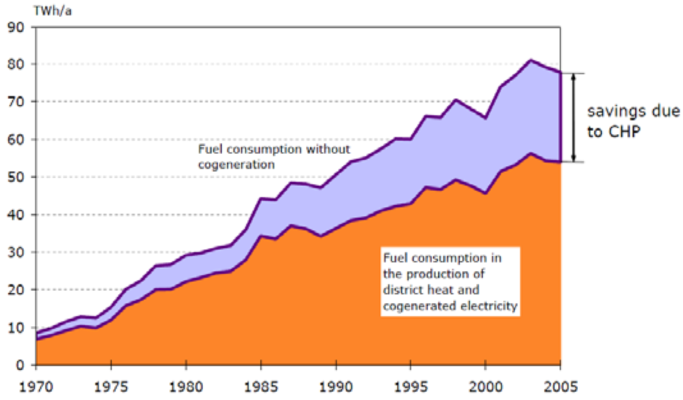
Finnish DH system was formed under the influence of market conditions in the economics. Great influence on DH system was exerted by the energy saving policy supported by the government. In the course of the development common approaches in the solution of technological problems of heat supplying were worked out. The efforts were aimed at creating reliable and high quality heat supply to the consumers at a reasonable price /4, p. 10/.

The main advantages of the developed in Finland DH system have become the following factors: the possibility of combined heat and electricity production, safety and beneficial for the environment approach in creation of highly integrated power system. DH system gives practically complete versatility as far as kinds of fuel are concerned. They can include fossil, renewable, and bio fuels. The usage of waste heat from different sources is also possible /4, pp. 11/.

4.3 Present state of Finnish district heating system

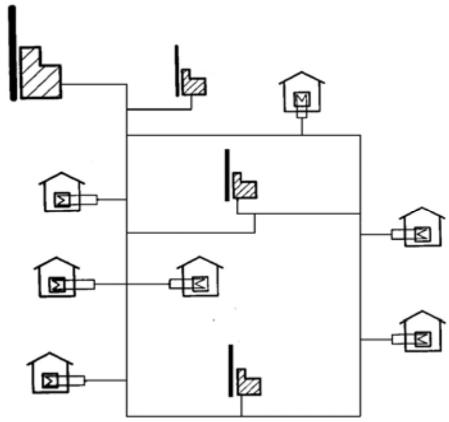
At present time in Finland closed system of heat supply with the independent connection of consumers is used. The advantage of this type of connection is that DH network and space heating network are two independent from each other systems. This means that in case of an accident on DH network and resulting stoppage of DH water delivery to the individual substation the water in the heating system will continue its circulation. Water circulation will allow to maintain normal thermal conditions during some period of time.

Finland is the world’s leader in the field of Combined Heat and Power (CHP) production. Of the total heat energy production amount 75% heat are produced by means of co-generation of heat and electric energy /12/. Production of heat energy at CHP plants is very efficient and allows fuel savings the amount of which is given in picture 14. And only 25% of the heat is produced in the Heat only Boilers (HOB).



Picture 14. Savings in fuel consumption due to CHP /12/.

Finnish CHPs work with almost constant load all the year round. A small number of peak demands during the coldest days in winter time are compensated with the help of several peak boilers situated in different DH network parts /4, p. 15/. The scheme of Finnish DH system is in picture 15. Finnish DH system is planned so that DH network may be a closed circuit which gives the possibility to optimize the heat producing plants. The closed circuit of DH system permits to supply heat energy to consumers during the whole year with minimum interruption.



Picture 15. Principle of district heating system in Finland /4, p. 17/.

In Finland two-pipe system is used. Heat supply to buildings is performed by independent scheme. In every building there is an individual substation. Each individual substation is equipped with heat exchangers, circulation pumps, automatic regulating fittings, heat energy counter, and automatic control devices. Automation system of the individual substation can regulate the operation according to the week days, and the time of the day taking into account the outside air temperature. Such a scheme of connection provides heat supply with the high degree of reliability. In case of failure of one of the individual substations, heat supply to the other buildings won't be stopped, as it happens in case with central substation. Internal space heating system is equipped with a thermostat valve at every heating device, which makes the system more customer-oriented and allows to save energy.

It should be noted that the heating system can start working at any time of the year as soon as it gets information about quite low temperature of the outside air. Centralized heat supply is built on the base of either modern boiler-houses, or CHP plants. In Finland it is considered that combined heat and energy production is economically profitable starting at 10 MW of electric power that is 35 - 45 MW of heat power.

An important factor for the efficient DH system operation is the level of the temperature in supply DH pipeline. Previously, Finnish DH system was planned with the temperature of water at +120^{0}C in supply pipeline of the DH network. At present the design temperature is +115^{0}C. One can suppose that the parameters of the temperature in DH network will be some more lowered with the aim to increase energy efficiency. Consequently, in order to compensate the demand in heat energy it is necessary to increase the amount of the delivered DH water. The lowering of DH water temperature will result in the increase of electric energy output at CHP plant. When DH water temperature is lowered, the pressure in DH network will become lower, too. As a result, reduced physical impact on the pipes will increase the service life of the pipelines.

Nowadays in Finland in wide usage there are prefabricated individual substations which are the functionally complete assemblies entirely manufactured at plants. They fulfill the following main functions: heat cold water for DHW system; provide water circulation in space heating and DHW systems; automatically regulate DH water consumption and distribution of heat inside the buildings; control parameters of DH water, water in DHW and space heating networks (pressure, temperature); protect internal networks against the accidental change of parameters; fill and makeup the internal networks.

5. DISTRICT HEATING SYSTEM RENOVATION PROBLEM IN RUSSIA

5.1 Danfoss company investigations

There were some attempts undertaken by foreign companies to change the existing in Russia situation by introducing modern and efficient standards of designing and operation of DH system. Unfortunately, those attempts were too rare and too few and did not have any considerable consequences.

With the purpose to renovate Russian DH systems by using modern equipment and European standards of regulating heat flows, Danfoss Company has carried out the investigations in two Russian cities, Moscow and Saransk /9/. The aim of the investigation was to compare the amount of heat energy consumption in a building equipped with an individual substation with a mixing valve, and in a building equipped with a modern prefabricated individual substation with heat exchangers, electronic weather compensator with precise automation system, automatic balancing valve, regulating valves and so on, and circulation pumps.

The existing space heating system was fitted with thermostat valves and individual heat energy counters. In DHW system, constant water circulation was provided. One more aim of the investigation was to get and maintain comfortable temperature inside the buildings, allowing the inhabitants themselves to set the desired temperature in every room and to pay only for really consumed heat energy.

To perform the investigation two residential buildings of typical development of late 1990s were chosen. In Moscow a seven-storey residential building with 83 flats was to be renovated. The building was connected to centralized heat supply system by independent scheme with the usage of four-pipe DH system. The space heating system was a vertical one-pipe system with radiators. Water for DHW was heated in heat exchangers installed in central substation. In Saransk a ten-storey residential building with 80 flats was chosen for the experiment. The building was connected to DH system by dependent scheme with two-pipe system.

Before the renovation, space heating and DHW systems were connected by individual substation equipped with a mixing valve. After the renovation, a prefabricated individual substation with heat exchangers for DHW system and with an automatic mixing valve for space heating system was installed.

It should be noted that with individual substation with a mixing valve the inhabitants of the buildings had to regulate internal thermal conditions of their flats by opening the windows, making draughts, covering heating devices with dense materials which may cause a fire. Thus, in some flats there was the overheating, while in the other flats there was the under-supply of heat energy. Payments for heating were made according to the norms calculated for 1 m^2 of total flat area.

5.2 The results of Danfoss Company experiment

After the installation of energy saving equipment in the buildings under the experiment, the control was carried out during one year and the following results were achieved /9, p. 6/.

1. The inside air temperature rose from 10 – 16^{0}C to 20 – 22^{0}C
2. DHW temperature got back to normal and was 60 ^{0}C according to designed conditions, resulting in water consumption reduction from 149 liters per person to 128 liters per person a day.
3. Average saving of heat during the winter time was 27 % and during the transition season 45 – 55 %.
4. Consumption of circulating water reduced by 28 %.
5. Economy of electric power used for DH water pumping was 15 %.
6. Volume flow of additional water (makeup water) in a boiler reduced by 39 %.
7. Maximum temperature of DH water rose from 104^{0}C to 115^{0}C.
8. The temperature of return DH water reduced by 6 – 8^{0}C.
9. Hydraulic conditions of DH system were improved.

The prefabricated individual substation installed by Danfoss Company allows providing reliable and uniform heat supply to all rooms of the building. Owing to the automatic system of weather compensation, the hot water temperature in the space heating system changes depending on outside air temperature. A metering unit provides the registration of the consumed energy amount. An individual heat energy counter motivates the consumer to save energy. Calculations of heat energy payments showed that the average cost of heating services in case of applying modern equipment had reduced by 30 - 40%, in comparison with the cost in buildings using individual substation with a mixing valve /9, p. 6/. The similar experiment was carried out in Russian town Irkutsk by Alfa-Laval Company. The results of that experiment are given in Appendix 3. Irkutsk is situated in more severe climatic zone of building than Moscow and Saransk. Therefore, the complexity of the task and the responsibility for making comfortable thermal conditions inside the building were even grater. Climatic parameters of the towns where the investigations were performed are given in Appendix 4.

5.3 Comparative analysis of two different schemes of district heating connection

While working at this bachelor thesis I investigated two multistory blocks of flats, one being 9-storied and the other being 24-storied buildings. These residential buildings were built in different periods, thus different techniques of designing DH and internal space heating systems were applied. Both buildings are situated in St. Petersburg. The purpose of the investigation was to control the change of thermal conditions and DHW temperature in heating and non-heating periods.

The first task of the investigation was measuring of thermal conditions in residential rooms. The investigation was performed in the cold season at the outside air temperature -15^{0}C and lower and in transition period at the outside air temperature from 0^{0}C to +8^{0}C, both in cloudy weather conditions. The second task was to measure DHW temperature at day-time and at night-time. Thermal conditions and DHW temperature were measured during the half of the year. Each parameter was measured not less than 7 times on different days. Thermal condition measurements were performed on the ground, the fourth and the top floors in the 9-storied building, and on the first, the twelfth and the top floors in the 24-storied buildings.

5.3.1 Direct and open scheme

The first investigated building, building N 1, is a 9-storied block of flats built in St. Petersburg in 1973. The building is connected by two-pipe DH system. The heating system of this building is connected by dependent scheme of DH connection with using non-automatic mixing valve. Space heating system is one-pipe. Radiators are not fitted with shut off valves. Thermostat valves are also not installed. DHW is connected by open scheme of DH connection. The DHW system is without a circulation pipeline.

In cold season thermal conditions of building N 1 didn't meet the parameters of indoor climate for residential buildings. Indoor air temperature was in the range from +16^{0}C to +18^{0}C. In transition season thermal conditions didn't meet the indoor climate parameters and energy efficiency requirements, either. Indoor air temperature was in the range of +24^{0}C to +27^{0}C. The results of the investigation showed that the DHW parameters didn't meet the requirements of safety and energy efficiency. At day-time during the heating season DHW temperature range was between +65 to +78^{0}C, at night-time it was from +20^{0}C to +25^{0}C. In non-heating period DHW temperature at day-time was +55 to +60^{0}C, which satisfied the requirements of safety. At night-time DHW temperature was +25 to +30^{0}C.

5.3.2 Indirect and closed scheme

The second investigated building (building N 2) is a 24-storied block of flats built in 2007. The building is connected by two-pipe DH system. Heating system is connected by independent DH connection scheme with using high speed heat exchangers, also called plate heat exchangers. Heating system is radial, with the usage of distribution and return manifolds. Every radiator is independently connected to the manifold. Every radiator is fitted with a shut off valve. DHW system is connected by closed DH connection scheme. DHW scheme is with the circulation pipeline.

Thermal conditions in building N 2 didn't meet the requirements of indoor climate parameters and the requirements of energy efficiency. Indoor air temperature in the cold season was +24 to +27^{0}C. In transition season air temperature was +26 to +28^{0}C. Under the influence of solar radiation it increased to +30^{0}C and even more. Parameters of DHW at day and at night during the heating period were +59 to +61^{0}C. During non-heating period of the year DHW temperature was approximately the same at day and night time and was +57 to +59^{0}C.

After considering the achieved results it was found that thermal conditions didn't satisfy specified requirements. Individual substation of this building was investigated in order to understand the reasons. Regulation of DH water coming into the heat exchangers of this individual substation was performed by hand. If it was necessary, service staff changed the position of the shut off valve depending on the outside air temperature. Such regulation does not provide the exact control of water temperature on the space heating side in accordance with the outside conditions that is weather compensation. The inhabitants of the building also could not control internal air temperature by means of the installed on radiators shut off valves as precisely as it would be possible to do by means of thermostat valves. It should be noted that automation system and modern regulating equipment were provided by the design, but in the course of the operation they were not used. It was because of the lack of highly skilled service staff necessary for maintaining such equipment.

6. CONCLUSIONS

Having considered the current situation with DH systems in Russia and the successes achieved in the field of heat supply in Finland, one may draw a conclusion that Russian DH networks need urgent renovation, taking into account and using Finnish experience of operating DH systems. It is quite expensive to solve the problem of increasing energy efficiency of DH system and making it more customer oriented by means of transition from centralized heat supply to individual sources of heat energy production. Such transition to individual boilers requires more investments than DH system renovation does /2. p. 75/.

However, the problem of renovation is also very complex and can’t be solved in one stage and in a short period of time. Therefore, planning a program of renovation one should clearly determine two parts of it: the long-term program and the tasks which can and have to be done now.

6.1 Long-term program of District heating system renovation

The main requirements for the renovation of Russian DH system are the modernization of heat energy sources, the introduction of combined heat and electric energy production according to European standards of optimization, and the improvement of means of conveyance and distribution of heat energy.

Later on it is necessary to continue the renovation of DH system and to pass from the central substation system to a system with individual substations. By installing completely automatic individual substation in every building it is possible to pass from four-pipe to two-pipe DH system which has a lot of advantages such as the following: the total length of DH pipes is shortened, which results in cutting down the expenditure of materials by 30 to 50%; investments for DH network maintenance are also cut down; expenditures for building and insulating materials are much smaller; heat losses in DH network are reduced by 20 to 30 %; consumption of electric energy used for conveyance of heat-carrying agent is reduced; owing to automatic regulation of heat supply to every particular consumer (a building) up to 15% heat used for heating purposes is saved; the time of construction is reduced /4, pp. 32-33/.

6.2 The tasks of current renovation of District heating system

In Russian conditions it is rather difficult to immediately change the entire system of conveyance and distribution of heat energy. Therefore, it is necessary to modernize central substations according to the recommendations of Finnish specialists. In every central substation it is necessary to install the following equipment: heat exchangers for DHW and space heating systems, automation system controlling the parameters of primary and secondary sides of the system, regulating valves, temperature sensors, and circulation pumps; and thus, to pass to an independent DH system. The control of space heating side should be performed taking into account the real heat energy needs and using modern automation systems.

For increasing energy efficiency of DH system it is necessary to aim at lowering heat load on DH system owing to: thermal insulation of the building, application of the method of programmed regulation of heat energy consumption, and usage of efficient thermal insulation of the pipelines. It is also necessary to work out recommendations for maintaining DH system pipelines in a satisfactory state (that is to organize modern repair work and anti-corrosion protection), to work out complex methods of designing the system of DH systems automatization. This automation system will allow to bring together the methods of heat balance of the building, calculation of the optimal load on the heating system depending on the purpose of the building and the kind of heating system, calculation of the load on the ventilation system and DHW system for residential, public, and industrial buildings. It should be noted that DH system has to work with minimum interruption in heat supply all the year round.

When DH systems, at present working by open scheme of heat supply, are to be renovated, in practice it is impossible to exactly copy Finnish DH system in conditions existing in Russia. The reasons of this are the following: expensiveness of the system, the huge scale of the renovated equipment, pipelines and subsidiary systems. When changing from two-pipe DH system with dependent connection of the internal systems to independent DH connection, it is necessary to enlarge the diameters of the pipelines of cold water supply systems. This should be made in order to provide enough water for DHW systems. This water is heated in heat exchangers in every building. At the water supply stations it is also necessary to increase the capacity of the installations for treatment drinking water used for the needs of DHW. Additional electrical energy is necessary for the circulation pumps operation. In order to pass to independent DH connection it is necessary to perform hydraulic calculation of all DH network pipelines. If carrying capacity of the pipeline is not enough, it should be changed for a pipeline of a large diameter.

Having taken into account all the above mentioned factors, one can conclude that such DH system renovation for the existing buildings in current economic conditions is very difficult. However, building norms and regulations should be revised taking into consideration Finnish experience in operating two-pipe DH networks with independent connection to the buildings. These changes will give the possibility to use Finnish DH system meeting all modern requirements in newly built districts. There are several attempts to use Finnish experience in Russia already. One of the examples is the 24-storied building which was considered in paragraph 5.3.2. However, the imperfection of the existing building norms and regulations does not allow to achieve rational energy efficiency and comfortable thermal conditions.

Thus, for renovation of Russian DH systems new norms of designing and maintaining should be worked out. It is necessary to detail very precisely how accurately the parameters in space heating and DHW systems will be maintained. Various influences on changing these parameters should be taken into account. For example, when designing DHW system it is necessary to determine the exact temperature differences in the supply and circulation pipelines, as it is accepted in Finland.

For designing individual substations it is necessary to introduce in Russian norms minimum quantity of automation systems which are obligatory for installation, and also to give the accuracy of maintaining parameters. It is also necessary to install thermostat valves on every heating device. Two-pipe scheme of heat supply should be used for DH system. Central substation should be transformed to the building level substations with heat exchangers for every system.

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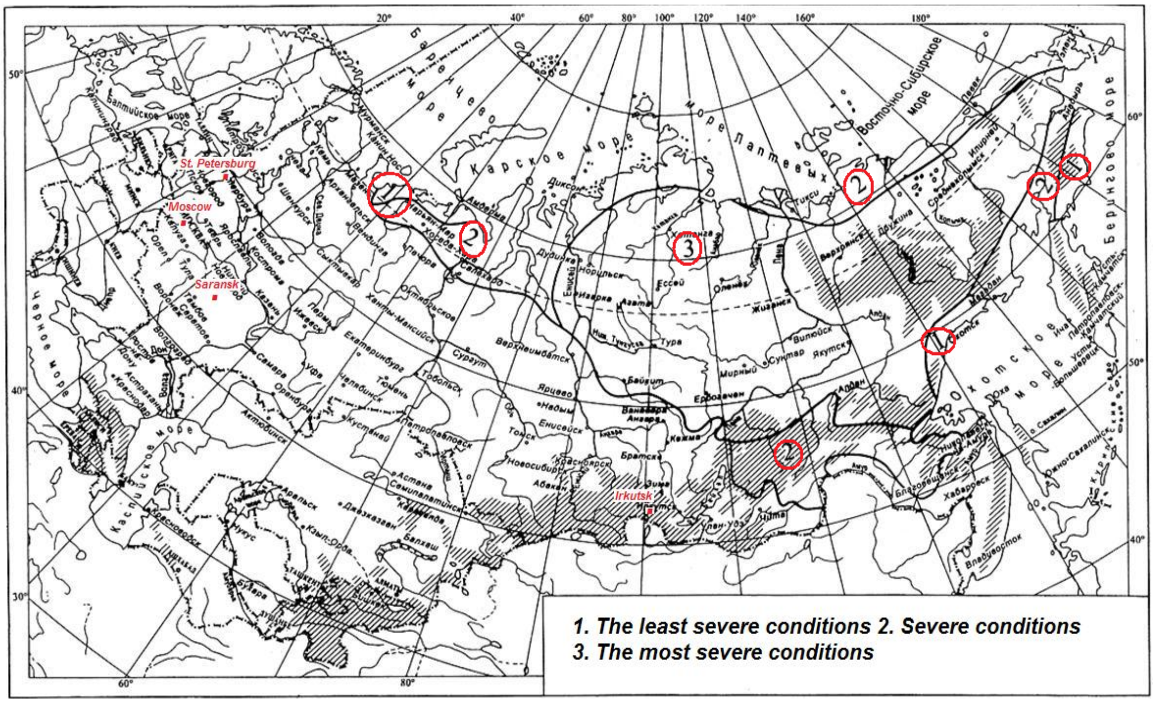
15. Alfa-Laval Company home page.

APPENDIX 1. District Heating – 2007 statistics /3, p. 392/.

	Unit	Finland	Russia	Sweden	Denmark	Norway
Number of District Heating utilities		≈ 150	11,183	140	450	55
Total installed DH capacity	MWh	20,390			17,266	1,400
Total length of DH pipeline system	km	11,000	176.512	17,782	27,575	900
Annual turnover in the DH sector		1.370 mill. €	19,500 mill. €	29 bln. Sekr	2,500 mill. €	164.7 mill. €
Employment fig-ures connected to the DH		3,700	44 mill. customers	4,800	1,848	
Number of house holds connected				2,027,85 0	1,5 mill.	
District heated floor space	m^2	801 mill. m^3		215 mill.	203,801, 958	
Total district heat delivered	Tj	108,360		169,200	102,806	11,313,00
Total district heat generated	Tj		6 887 286	198,296	120,983	12,064
Energy supply composition for district heat generated						
• Renewable		11.60 %		4%	17,2%	15
• Waste				17.4%	20.0%	33%
• Heat Pumps				6.2%		8%
• Industrial surplus heat		1.60 %		7.2%	2.7%	11%
• Coal and coal products		25.50%	17.60%	4.1%	27.1%	2%
• Natural gas		33.90%	72.70%	3.9%	29.0%	5%
• Oil and pe-troleum products		3.90%	6.90%	4.1%	4.0%	6%

• Electricity			0.30%	3.6%		20%
• Other		23.70%	2%	6.5%		
CO_2 emission of district heat				20 g/MJ	45g CO_2/MJ	
Total heat demand 2007	Tj		8 457 336 (2000)	898,754	325,000	233,812
Total share of CHP of national electricity production				5%	52,9%	
Installed capacity of CHP heat auto production	MWth			1,100 MW	1,500	
% of DH used to satisfy heat demand in the residential and services and other sectors			63%	55%	29%	4.8%

APPENDIX 2. Climatic map /14, p. 63/.



APPENDIX 3. Climatic parameters of Irkutsk, Moscow, and Saransk /14, pp. 5, 8, 9/.

Town	The temperature of the air on the coldest day, ^{0}C Provision		The temperature of the air during the coldest five days, ^{0}C Provision		The temperature of air, ^{0}C Provision	Absolute minimum temperature of the air, ^{0}C	Geographical coordinates	
	0.98	0.92	0.98	0.92	0.94		North latitude, ^{0}	East longitude, ^{0}
1	2	3	4	5	6	7	8	9
Irkutsk	- 40	- 38	- 38	- 36	- 26	- 50	52	104
Moscow	- 36	- 32	- 30	- 28	- 15	- 42	55	37
Saransk	- 38	- 34	- 34	- 30	- 17	- 44	54	45

APPENDIX 4 (1). The results of ALFA-LAVAL Company investigation /15/.

№	Item	Old solution	Heat substations	Improvement
1.	Total heat demand, Gkal/h	17,4	13,8	3,6 / 20%
2	Heat consumption, Gkal	99326	72512	26814 / 27%
3.	DHW consumption, l/person/day	148	119	29 / 19%
4.	Used primary temperature difference, C	30	60	30 / 66%
5.	Water adding in boiler plant, cub.m/h	228	139	89 / 39%
6.	Network pump flow, cub.m/h	890	640	250 / 28%
7.	Network return temperature, C	76-78	70	7-8 / 20%

APPENDIX 4 (2). The results of ALFA-LAVAL Company investigation /15/.