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IEA DHC|CHP

International Energy Agency
IEA Implementing Agreement on District Heating and Cooling, including the integration of CHP

DISTRICT HEATING DISTRIBUTION IN AREAS WITH LOW HEAT DEMAND DENSITY

ZW ENERGITEKNIK

BB Energi-teknik

VTT

IEA R&D Programme on

"District Heating and Cooling, including the integration of CHP"

District heating distribution in areas with low heat demand density

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Preface

Introduction

The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries and reduce the dependency on oil and other fossil fuels. Thirty years later, the IEA again drew attention to serious concerns about energy security, investment, the environment and energy poverty. The global situation is resulting in soaring oil and gas prices, the increasing vulnerability of energy supply routes and ever-increasing emissions of climate-destabilising carbon dioxide.

At the 2005 Gleneagles G8 an important role was given to the IEA in advising on alternative energy scenarios and strategies aimed at a clean, clever and competitive energy future. Two years later, at the Heiligendamm G8, it was agreed that "instruments and measures will be adopted to significantly increase the share of combined heat and power (CHP) in the generation of electricity". District Heating and Cooling is an integral part of the successful growth of CHP: heat networks distribute what would otherwise be waste heat to serve local communities.

The IEA is active in promoting and developing knowledge of District Heating and Cooling: while the DHC programme (below) itself is the major global R&D programme, the IEA Secretariat has also initiated the International DHC/CHP Collaborative, the kick-off event of which took place in March 2, 2007 with a 2-year Work Plan aiming to raise the profile of DHC/CHP among policymakers and industry. More information on the Collaborative is to be found on IEA's website www.IEA-org.

The major international R&D programme for DHC/CHP

DHC is an integrative technology that can make significant contributions to reducing emissions of carbon dioxide and air pollution and to increasing energy security.

The fundamental idea of DHC is simple but powerful: connect multiple thermal energy users through a piping network to environmentally optimum energy sources, such as combined heat and power (CHP), industrial waste heat and renewable energy sources such as biomass, geothermal and natural sources of heating and cooling.

The ability to assemble and connect thermal loads enables these environmentally optimum sources to be used in a cost-effective way, and also offers ongoing fuel flexibility. By integrating district cooling, carbon-intensive electrically-based air-conditioning, rapidly growing in many countries, can be displaced.

As one of the IEA's 'Implementing Agreements', the District Heating & Cooling programme is the major international research programme for this technology. Active now for more than 25 years, the full name of this Implementing Agreement is 'District Heating and Cooling including the integration of Combined Heat and Power'. Participant countries undertake co-operative actions in energy research, development and demonstration.

Annex VIII

In May 2005 Annex VIII started, with the participation from Canada, Denmark, Finland, the Netherlands, Norway, South Korea, Sweden, United Kingdom, United States of America.

Below you will find the Annex VIII research projects undertaken by the Implementing Agreement "District Heating & Cooling including the Integration of Combined Heat and Power".

Project title	Company	
New Materials and Constructions for Improving the Quality and Lifetime of District Heating Pipes including Joints – Thermal, Mechanical and Environmental Performance	Chalmers University of Technology Project leader: Ulf Jarfelt	8DHC-08-01
Improved Cogeneration and Heat Utilization in DH Networks	Helsinki University of Technology Project leader: Carl-Johan Fogelholm	8DHC-08-02
District Heating Distribution in Areas with Low Heat Demand Density	ZW Energiteknik Project leader: Heimo Zinko	8DHC-08-03
Assessing the Actual Energy Efficiency of Building Scale Cooling Systems	International District Energy Association Project leader: Robert P. Thornton	8DHC-08-04
Cost Benefits and Long Term Behaviour of a new all Plastic Piping System	NUON Project leader: Hans Korsman	8DHC-08-05

Benefits of membership

Membership of this implementing agreement fosters sharing of knowledge and current best practice from many countries including those where:

DHC is already a mature industry

DHC is well established but refurbishment is a key issue

DHC is not well established

Membership proves invaluable in enhancing the quality of support given under national programmes. Participant countries benefit through the active participation in the programme of their own consultants and research organisations. Each of the projects is supported by a team of experts, one from each participant country. As well as the final research reports, other benefits include sharing knowledge and ideas and opportunities for further collaboration.

New member countries are very welcome - please simply contact us (see below) to discuss.

Information

General information about the IEA Programme District Heating and Cooling, including the integration of CHP, can be obtained from our website www.iea-dhc.org or from:

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The IA DHC/CHP, Annex VIII, also known as the Implementing Agreement District Heating and Cooling, including the Integration of Combined Heat and Power, functions within a framework created by the International Energy Agency (IEA). Views, findings, and publications of the IA DHC/CHP do not necessarily represent the views or policies of all its individual member countries nor of the IEA Secretariat.

Executive Summary

Background

In many countries with long district heating tradition, such as is the case in Scandinavia, district heating is well developed and the market development has been slowed by increased use of energy efficiency measures in buildings. When available at all, district heating reaches often about 80 - 90 % of the central city area. In the areas with lower heat demand density surrounding the city centre, often only 10-15 % of the buildings are connected to the district heating system. One way to allocate an increased market share to district heating is to apply new measures/techniques for supplying heat into areas with lower heat demand density that to date have not been considered economically suitable for district heating. Among the investigated alternatives are measures for making heat distribution more efficient as well as new heating applications. As a result, heat distribution in areas with low heat demand density could be done more effectively and at lower cost.

The objective of this project is to propose and to analyse measures for improving the economy of heat distribution in areas with low heat demand density. The consequent application of these measures will not only reduce distribution costs but also the environmental impact of energy use in these areas.

Systems with low heat density are struggling with relatively high investment costs and high heat losses. One way to reduces these costs would be to make components smaller and lower the amount of groundwork in the distribution net. Another way is to distribute more energy in the same piping structure, hence decreasing the relative amount of fixed costs of the delivered energy. Therefore, in this report we are first presenting new technologies that are on the frontier for application in district heating systems. This holds as well for the heat distribution system as for systems using heat. We describe technologies that have been used in demonstrations projects or in real projects such as new types of pipes (i. e. triple pipes) or only just in the laboratory (egg-shaped pipes). For the same purpose, we present new distribution methods, such as small service pipes with booster pumps or small pipes in combination with heat storage units. In addition, we describe components and measures, which can gain worldwide interest for their capability of replacing electricity by heat, in our case district heat.

Cost analyses are critical for the outcome of this report. By analysing real systems, we were able to calibrate other programs used for cost calculations. Because project costs can be very site-specific and costs of different systems on different places are usually very difficult to compare, we concentrated in this project on the cost comparison of systems constructed with comparable cost structures. These system comparisons were applied on the systems analysed from Finland and Denmark, leading to some general conclusions about the systems to be used in areas with low heat density.

Concerning the use of energy, we are presenting measures for increasing district heating loads without wasting energy. We give example of systems in which the use of district heat is increased at the expense of electricity use. Households can be provided with equipment such as heat driven washing machine, dishwasher and tumble-drier. In the future, people may want to increase their comfort by using air-conditioning, pools and spa-tubs and possibly other equipment such as car heaters and greenhouses, all of those supplied with district heat instead of electricity. This saves not only electricity for other and exergetically more favourable applications, it will also help to ***compensate for decreasing heat loads*** and to maintain heat distribution efficiency.

Content of the report

The report contains the following main chapters dealing with the questions of heat demand, distribution systems and new loads suitable for areas with low heat demand density.

Chapter 1 - "Introduction" presents the background and introduces the problem area.

Chapter 2 - "Heat demands for district heating" - discusses after the Introduction the basic load conditions for practical district heating networks and describes the relation of heat density and line heat demand. It also shows examples for the lower limits of heat density in district heating and elucidates how measures for energy saving on the one hand and new district heating loads on the other hand can shift these limits.

Chapter 3 - "Examples of applications with low heat demand" describes examples from sparse district heating applications realised in Sweden, Finland and Denmark. The intention of this chapter is to show how district heating is used in areas with low heat demand density, and which losses and other typical system conditions are prevailing for such systems.

Chapter 4 - "Evaluation of loads in district heating systems with low heat demand density" describes the evaluation of two systems with low heat demand density: Neidonkallio near Espoo, Finland and Peter Freuchenvej in Nykøbing/Falster, Denmark. In Neidonkallio, the energy for space heating is delivered via substations with two heat exchangers in parallel, one for space heating and one for hot water preparation. In the Peter Freuchenvej-system, this solution is used in a couple of buildings, whereas the majority of the buildings have direct-connected radiators and a hot water storage tanks fed by district heating.

Chapter 5 - "Techniques for reduction of piping costs and heat losses from heat distribution networks" discusses methods and techniques that in recent years have been developed especially for areas with low heat demand density. A great deal of the development has been achieved in development projects in Denmark, Sweden and Finland. Compared to standard technology, these achievements concern new material for pipes and insulation, new design of pipes, methods for routing district heating pipes, and in addition how to reduce heat losses by other measures, i. e. reduction of pipe diameter in combination with advanced flow control.

Chapter 6 - "Cost model for heat distribution systems in areas with low heat demand density" presents a simple cost model for local district heating systems to be used for applications with low heat density. The model itself is based on spreadsheets created in Excel that are constructed so that they show system costs for alternative construction layouts applied on the same system. This cost model is applied on the two system analysed in detail for this report, i.e. and Neidonkallio and Nykøbing.

Chapter 7 - "Increased use of district heat instead of electricity in households" shows how the load of detached houses can be increased, partially by shifting the energy use from electricity to district heating. The chapter describes methods for increased utilisation of district heating that were demonstrated in a project in Gothenburg, Sweden. It also describes how the total load would change if some of these loads were to be used in row houses in Neidonkallio.

Chapter 8 - "Improved system solutions" describes results of system analyses performed to illustrate eventual cost saving that can be received by careful system design. Essentially, the main changes are use of twin pipes instead of single pipe systems, use of smaller pipe dimensions, eventually with booster pump, varying insulation thickness, new routing (house-to-house) and the use of hot water tanks instead of directly connected hot water preparation. Two systems, one in Finland (Neidonkallio) and one in Denmark (Nykøbing/Falster) are investigated.

Chapter 9 - "Connection of future areas with low heat demand density". This chapter summarises the most important items for achieving cost-effective connection of buildings in areas with low heat demand density, for example small customer loads such as detached houses. The chapter presents a checklist of items that are important for cost reduction when planning a district heating distribution net, either for an area with existing detached houses or for new development. Minimizing pipe dimensions and groundwork is important in any case. In addition, different ways to connect substations are discussed. Finally, the importance of reaching a high degree of connection for local district heating net is underlined.

Chapter 10 - "Conclusions" summarises the quintessence of the work and gives recommendations for future applications.

Chapter 11 collects all *"References"*.

Additional information about how to calculate heat losses and further costs comparisons for alternative system solutions are collected in the *Appendices*.

Final conclusions

A main conclusion of this report is that a number of techniques and measures are available to help reduce costs for heat distribution in areas with low heat demand density. Expressed in terms of heat densities, we believe that areas with a heat density of 10 kWh/m^2,yr or with line heat demand of 0.3 MWh/m,yr can be economically served by district heating.

Based on a number of projects, it has be determined that district heating, in order to achieve good economy for low heat demand density, requires more careful planning than traditional district heating. In many cases, alternative solutions that do not follow the traditional district heating manuals can be successfully applied and will give lower costs. Some of these alternative solutions may in the future find their way into handbooks for sparse district heating design, while others for now must be considered as unusual measures and analysed carefully before being applied.

The first preinsulated networks were in use in the late 1960'ties and thus many old systems are in need for renovation. The recommendations given here for better design and reduced heat losses in new DH systems are of course also valid for the renovation of old systems.

The following provisions have been found to affect the total costs of connection to district heating:

System design

- Examples from Denmark have shown that *low pressure and low temperature systems* with direct connection of the radiator system can reduce costs. Such systems can either be used in small local networks or as secondary systems connected to main district heating systems.
- System design that *reduces pipe dimensions* is important in design of systems for detached houses. Such systems can be systems with *hot water accumulators* instead of directly connected heat exchangers, or service pipes with reduced diameter and ultimately even a *booster pump* for adequate heat supply.
- House-to-house connection is already a classical way to connect detached houses. However, it is difficult to get the customer interested due to larger impact on their premises. On the other hand, in connection with lower system costs and rewards for own work, it is possible to implement this method of reducing connection costs.
- The *degree of connection* is an import issue for both the utility and the customer, because the fixed costs decrease with the number of customers. This accentuates the importance of investment in marketing and dissemination of information to the potential customers from the very beginning of a project dealing with new connections to an area.

District heating pipes

Pipes have a twofold impact on the system costs: *Investment and heat losses*. All measures that can reduce one of these are of interest, such as good *insulation performance* and *advanced pipe design*.

- The thermal conductivity of polyurethane insulation depends on the temperature as well as on the time elapsed since the foam was produced (ageing). Heat losses and heat loss coefficients can be accurately calculated for single, twin and triple buried heating pipes.
- New types of pipe systems are compared in respect to their possible installation costs and heat losses. *For an 80 mm (nominal) distribution pipe,* we compared a pair of single pipes with a *circular twin pipe* and with an *egg-shaped twin pipe*. We found that the egg-shaped pipe reduces the heat loss by 37 % and the investment index by 12 % compared with the pair of single pipes.
- For *service pipes* a pair of single pipes ø 25/77 mm is the reference case. We found that the *triple pipe* (a system with two smaller supply pipes and one return pipe, one of them used in the case of high hot water consumption) reduces the heat loss by 45 % compared with the reference case and by 24 % compared with a *circular twin pipe*. The reduction in

investment index can be up to 20 %. New alternative designs of service pipes, involving a combination of co-insulation, asymmetric insulation, and dissimilar dimensions of two or three media pipes, have the potential to achieve saving of roughly 50 % compared with traditional pair of pipes.

- *Service pipes* should be as small as possible and no reserve capacity should be calculated for. Similar holds also for the distribution pipes. Taken future energy saving measures into account, reserve capacity should only be taken into consideration if it is obvious that additional loads will be connected in the future.

Civil works

The classical trench design is for double pipes with drainage bed. In accordance with local conditions, the trench can be made smaller with corresponding reduction of excavation work and handling of soil volumes. The following measures are possible:

- The use of twin pipes is mandatory in systems with low heat demand density. The reduction of excavation work is a clear cost advantage.
- Reduction of pipe dimension may in many applications result in a smaller trench, which should be taken advantage of if possible.
- Reduced ground cover can be applied in piping without traffic loads. Hence, the routing should take advantage of such possibilities (parks, gardens, sidewalks).
- Drainage bed pipes can often be omitted, especially in trenches for service pies.

New loads

District heating systems should be marketed to new customers with an additional benefit: District heating can deliver part of the energy, which to date has been supplied by electricity. Eventually, this could cover a broad spectrum of applications. In the beginning, new applications could be the white goods *washing machine*, *disk washer* and *tumble dryer*. Small absorption cooling for air conditioning systems and heating of pools and spa-tubs are other potential applications.

An example is a demonstration of new loads in Gothenburg (Sweden): There it was shown that 7500 kWh of district heating could replace 5500 kWh of electricity. This application resulted in 35 % reduction of primary energy (based on power generated from a coal condensing power plant).

Evaluation and system analysis

System analyses have been verified with system simulations for Neidonkallio and Nykøbing/Falster. The analyses compare the total cost for different pipe systems and district heating solutions, such as: single pipes, twin pipes, triple pipes, reduced pipe dimensions, systems with booster pumps in service pipes and systems with hot water accumulator instead of direct hot water heat exchanger. The results of these analyses conclude that costs could be reduced by about 25 % in smaller systems (Nykøbing/Falster) and by 40 % in larger systems (Neidonkallio).

Table of Content

1 Introduction

District heating in a decreasing market

In many countries, especially in Scandinavia and Germany, district heating is well developed but the market development is slowed down by an increased use of energy efficiency measures in buildings. District heating often covers about 80-90 % of the central city area were it is established. In the lower heat demand areas surrounding the district heated area, eventually only 10-15 % of the buildings are connected to the district heating system. Those areas are mainly rural regions and peripheral areas of cities. One way to allocate an increased market share to district heating in these areas is to apply new measures/techniques for supplying heat that so far were not considered economically suitable for district heating.

The question of new district heating markets is especially of interest for municipalities that have been using district heating systems for a very long time. In such municipalities, the degree of connection is very high, usually around 90 % or more of the possible heat load. This results in very high heat demand density and in generally effective systems. However, with the new trends of energy efficiencies in buildings, the additions of new customers cannot compensate for the reduction of energy use in existing buildings, which poses a problem for the district heating utilities. In traditional district heating systems, the heat source is waste heat from combined heat and power plants or industry. In such plants, the waste heat has to be used by the DH-system or ”wasted” by another cooling device, or the electricity production has to be shifted towards increased amounts of condensing power production. In that case, the plant is working less efficiently and less friendly to the environment in response to the decreasing market. Utilities want to compensate for this lack in energetic and environmental efficiency by supplying new markets with heat and/or cooling. This, however, can only be done by connecting new loads and those will be normally found in areas with lower heat demand density outside of the central parts of a city. These are normally areas with detached houses, service centres, suburbs, and so on. Smaller amounts of energy will be distributed to larger areas. Thus, while the heat demand density (in kWh/m²) decreases, the relative heat losses increase. At given point a limit is reached were it is no longer economic or efficient to supply heat. Due to the increasing need for electricity and increasing energy conservation measures, more and more heat must be supplied to areas with increasingly lower heat demand density.

This project will analyse new possibilities for heat distribution to areas that conventionally are considered to be near or below the economic threshold with the aim of accomplishing a more efficient supply of district heat in such areas. Among the investigated alternatives are new heating applications as well as measures for making heat distribution more efficient. As a result, heat distribution in areas with low heat demand density can be accomplished more effectively and at lower cost.

The objective of this project is to propose and to analyse measures for improving the economy of heat distribution in areas with low heat demand density. The ubiquitous application of these measures will not only reduce distribution costs but also the environmental impact of energy use in these areas. As a result, in the long run, district heating will be extended into areas that so far have not been considered economically worthwhile to be supplied with district heat.

The challenge for an international project of this kind is to produce results which are valid on a rather global basis, or at least for the majority of the IEA community. As far as district heating is concerned, this issue is legitimate because district heating has grown from different technical histories and in different types of societies. In principle, the Northern and Eastern European countries have a long tradition with collective systems and therefore district heating is very widely accepted in these countries.

In spite of this situation, the historical development of district heating techniques differs quite a lot among these countries and measures that would be preferred in one country might be unacceptable to another country. Furthermore, there are of course substantial differences in the economies among countries including the way to calculate profits, thus given measures can be economically viable in one country but maybe not in an other one. The situation gets still more complicated if we include countries without a district heating tradition such as Southern European countries and the countries on the North American continent.

It should be mentioned that the situation in Denmark is different from that in Sweden and Finland. More than one million detached houses are connected to the DH networks and consequently the

line heat density is generally lower in Denmark, on the average around 1 MWh/m,yr. Many of these networks are old and in need of renovation. In this context, the present project will show some Danish examples to reduce the costs and heat losses by reducing the necessary pipe dimensions.

Consequently, ***different measures for increased effectiveness*** of heat distribution might suit some countries, but may not be applicable or economic in others. Readers will have to make up their own mind about the usefulness of a proposed measure or technique. Even within one and the same country, experts do not very often agree upon the usefulness of a certain measure. It increases the charm of such a project that researchers can sometimes put a finger on a debated point by showing facts and figures, whereas others are referring to traditions. An example of that is the use of hot water accumulators in district heating systems. On the other hand, the use of ***new district heating loads*** such as some appliances and absorption chillers, will not only be limited to district heating systems, but can be applied everywhere hydronic heating systems are used, e.g. in systems using solar energy, heat-pumps and biomass boilers. This idea for replacing high-grade energy from electricity with low-grade heat will therefore be much more generally applicable.

The work in this report deals with two technical approaches to the question of heat distribution efficiency. One is the ***way of distributing heat*** to customers with low or even very low house loads, as it is the case in areas with modern detached houses. The investigated areas of Neidonkallio in Finland and Nykøbing on the Island Falster in Denmark are examples of that. For both areas, alternative new ways for heat distribution and house connections have been analysed and compared with traditional solutions.

These houses – on the other hand – are equipped with household appliances such as electrically driven washing machines, dishwashers and tumble-driers. In the future, people may want to increase their comfort by using air-conditioning, pools, hot-tubs and maybe other equipment such as car heaters and greenhouses. All of these also operate electrically. Consequently, what we are seeing here is an increased use of electricity in a continuously shrinking heat market, resulting in an unsolvable equation. Instead, such equipment can be operated by district heat as demonstrated by a project in Gothenburg (Zinko, H. et al., 2006). This would not only save electricity for other and exergetically more favourable applications, but it will help to ***compensate the decrease of heat loads*** and help to keep the heat distribution efficient.

Similar arguments also apply to new district heating areas, which are often common in rural areas. There, heating-only boilers are often supplying heat to areas with predominantly low heat demand density. In this case, it is important from the beginning to choose inexpensive solutions for the heat distribution system and measures for heat distribution. Of course, new types of district heating loads will be required in such areas as well. But we will exclude solutions with combined use of DH and RES (solar heating/heat pumps) and although we will consider variable supply temperatures, we will not consider temperatures that are so low that a back-up with electricity or solar energy for hot water preparation in the summer is necessary.

Content of the report

The report is divided in main parts dealing with distribution systems and new loads suitable for areas with low head demand density.

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Chapter 2 - "Heat demands for district heating" - discusses after the Introduction the basic load conditions for practical district heating networks and describes the relation of heat density and line heat demand. It also shows examples for the lower limits of heat density in district heating and elucidates how measures for energy saving on the one hand and new district heating loads on the other hand can shift these limits.

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Chapter 10 - "Conclusions" summarises the quintessence of the work and gives recommendations for future applications.

Chapter 11 collects all *"References"*.

Additional information about how to calculate heat losses and detailed costs calculations for alternative system solutions are collected in the *Appendices*.

Experts group

As mentioned in the preface, this project was performed as one of the projects within the IEA-District Heating and Cooling Program, Annex XIII. In such a project, an Experts group supports the project team with ideas and a wealth of experience. They form a panel that helps to develop the essential concepts of the project. Of course, it also assists the researchers of the project group in getting all the technical details understandable and right. Such a counsel is an invaluable help in this type of project. Therefore, we are very grateful to the following members of the Experts group for their assistance:

Gunnar Nilsson, Göteborg Energi AB, Sweden.

Dr. Chris Snoek, CANMET Energy Technology Centre-Ottawa, Canada.

Jonathan Williams, Building Research Establishment Limited, BRE, United Kingdom.

Veli-Pekka Sirola, Finnish Energy Industries, Finland and Rune Volla, Viken Fjernvarme AS were corresponding members of the Experts group.

Assistance from other experts

The project received also valuable assistance by other experts, not members of the Experts group but well engaged in several ways with their experience in the project:

Charlotte Reidhav, Göteborg Energi AB and Chalmers Technical University, Sweden

Kurt Paaske Christensen, Morten Dalby and Lars Frederiksen, Guldborgsund kommune, Denmark.

The cooperation

The project is a result of the cooperation of the following three institutions:

The consultant company **ZW Energiteknik AB from Nyköping, Sweden** was the project organiser with Dr. Phil Heimo Zinko as the project leader and editor of the report. To his help and co-worker within ZW he had Ulrika Ottosson, who contributed with a special program for cost calculations of alternative types of distribution systems. Much of the Swedish input to the work was based on the experience that has been systematically elaborated by the Swedish District Heating Association in a special program called "Värmegles Fjärrvärme" (District heating with low heat demand).

Kari Sipilä and Miika Rämä at **VTT, Finland** have been responsible for the case study of Neidonkallio in Kirkkonummi. The DH-system of Neidonkallio is designed and simulated with VTT's network model. The original DH-network is compared to some new construction ideas to build up the regional heating network and some new ways to use it.

Benny Bøhm at **Benny Bøhm Energiteknik, Denmark,** contributed to the project with his extensive experience in research on district heating technologies and energy-economics. He is also working part-time at MEK DTU. His main interests are in improved thermodynamic performance of energy systems, in particular in efficiency and heat loss determination from distribution networks, in thermodynamic performance of house stations and in the combined effect on design and optimum operation of district heating systems. Part of the contribution by Benny Bøhm was elaborated in cooperation with Halldor Kristjansson, **Danfoss DH,** who is en expert on customer installations and pipe systems.

Acknowlegement

The authors whish also to thank Dr. Gary Phetteplace, GWA Research, LLC, USA, for the important work with language checking parts of this report. It was not our goal that this report be an English textbook, but through the assistance of Gary Phetteplace, as well as of the members of the Experts Group Chris Snoek and Jonathan Williams, we can trust that it will be understandable for everybody with a technical education.

All authors also have the pleasure to acknowledge the engagement of the national district heating associations of Denmark, Finland and Sweden by giving both financial and technical support to the project.

2 Heat demands for district heating

Summary:

This chapter discusses the basic load conditions for practical district heating networks and describes the connection of heat density and line heat density. It also shows examples of the lower heat density limits for district heating and explains how measures for energy saving on the one hand and new district heating loads on the other hand can shift these limits.

2.1 Heat demands for district heating

The two main investments in a district heating system are the heat production plant and the network. The heat production plant is a single investment; the cost of it depends on the total annual amount of heat load of the area. The investment in the pipe system, on the other hand, is a question of the length of the pipe network within the area of the heat supply and therefore is dependent on two dimensions: Thermal length and thermal width. Therefore, it follows that the costs of the distribution network can vary appreciably for different network geometries and type of systems.

The traditional way of planning heat distribution systems starts from a heat density map for the area to which heat should be provided. In such a map, the areas with high heat densities are easily identified and the extent of the central district heating network can be determined. In such a development process, areas with high and medium heat densities will initially be the main areas of interest for district heating. Very often, the core heat densities (expressed in annual heat demands) would be larger than 50 kWh/m²,yr, which normally is on the safe side of being a profitable investment for district heating. In most cases, the heating utility is not only interested in delivering heat at the best profit but also in delivering as much heat as possible as long as the marginal profit is positive. Therefore, the utility also examines the areas around the thermal core, investigating the planned and probable development of these areas and thus designating further areas to which the district heating should be delivered. These areas are usually areas with lower heat demand density and it is up to the skilfulness of the developer to connect these areas in such a way that the investment will be paid back in reasonable time.

2.2 The line heat density

In order to gauge the profitability of a certain investment in a district heating distribution network, the line heat density is a practical concept. Because the heat is distributed through DH-pipes, the term “line heat density” better reflects the dimensions and length of the pipes involved in the heat delivery and the costs connected with it. Compact building areas with multifamily residential buildings connected to a district heating network usually exhibit high line heat density, whereas areas with detached houses normally show low line heat density, see Figure 2.1. This Figure shows a typical city area with a combination of high, medium and low thermal densities. In our context, the areas with low thermal densities are of particular interest. The total costs for district heating are the sum of the annual investment costs for heat generation, distribution network, customer installations as well as the energy costs including heat losses and costs for pumping and maintenance. When making a decision, whether to build a district heating system or not, the sum of these costs has to be compared with corresponding costs for alternative heating systems.

When connecting new housing areas to an existing district heating network, only marginal costs for investments in pipe system and marginal energy costs have to be included. This is the reason why it can be profitable to connect areas with low heat densities that normally would not be profitable when a completely new system has to be built.

2.3 Towards low line heat densities

An example is shown in Figure 2.2. In this diagram, heating costs are plotted as a function of the line heat density for both district heating and individual oil heating according to Kristjansson et al., (2004).

According to this Danish study, the breakeven point for district heating is at line heat densities of 0.2 MWh/m,yr for conventional pipe dimensions and 0.15 MWh/m,yr for systems with reduced dimensions. The latter value can be considered a very low value, indicating that it could be

economically possible to connect modern detached houses with an annual heat load of 14 MWh at a mutual distance of 100 m, if the pipes are dimensioned carefully, allowing for small dimensions

Figure 2.1: Thermal map of a district heating area showing areas with different thermal densities. Example for city area. Lines of equal heat densities are shown: 5 - 10 - 15 - 20 - 23 kWh/m² (Siwertz, 2007).

and accepting pressure drops up to 2 MPa/km, i.e. much higher than in classical design. This means in practice that district heating can be delivered far out to the periphery of city areas. The smaller dimension not only reduces the piping costs, it also reduces the heat losses of the

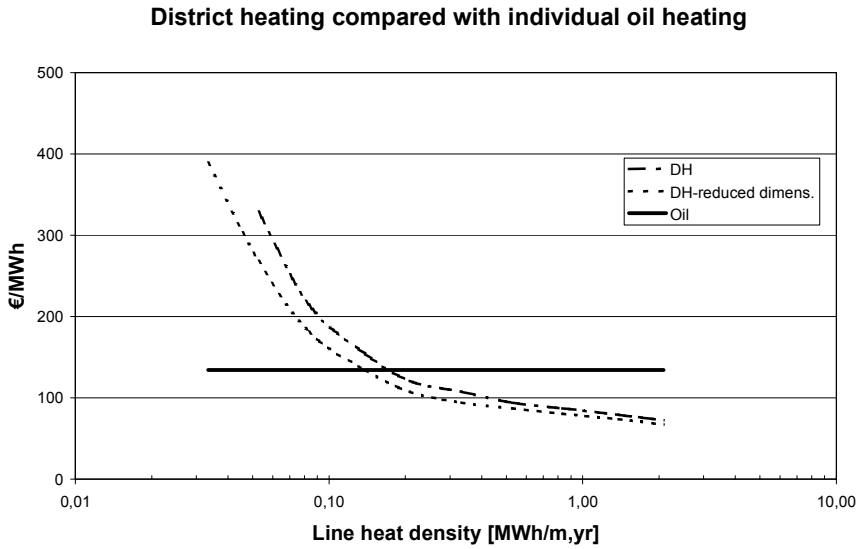


Figure 2.2: Comparison of heating costs for district heating and oil heating as a function of line heat density (Kristjansson et al., 2004).

distribution system, the cost of which is often neglected, but which is very relevant at low heat line densities, see Figure 2.3.

In this diagram, the relative heat loss is shown as a function of the line heat density for 250 Danish district heating systems. As shown in Figure 2.3, showing a majority of Danish systems with line heat densities of 1-2 GJ/m,yr (0.28-0.56 MWh/m,yr), the relative heat loss in a network with very low line density can be as high as 80 %, if special measures are not undertaken. In a special approach with pipes carefully designed for lower dimensions, the heat losses are reduced towards 32 % for the same line heat density.

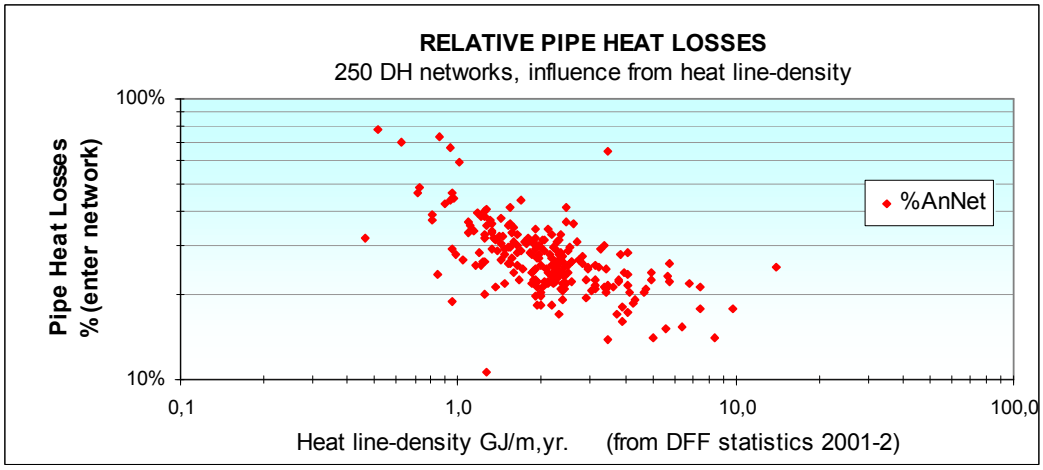


Figure 2.3: Relative heat loss for Danish district heating systems as a function of heat line density (Kristjansson, 2004).

2.4 The concept of thermal width

In order to further distinguish suitable areas for district heating, the concept of thermal width was introduced by Sven Werner (Werner, 1997). In Figure 2.4, this concept is illustrated. Depending on the network-design, an area with a certain thermal density can have different thermal length and thermal width (Larsson, Andersson, Werner, 2002). The same also holds for areas of the same size, but different shapes.

The following relation holds for the effective thermal width W:

$$W = \frac{A}{l_p + \frac{l_s}{c}} \quad \text{(W in meter).}$$

with

A = Area of interest

l_p = length of main pipes

l_s = length of service pipes

c = degree of connection of customers.

A given area with larger thermal width will generally show lower pipe length and therefore lower connection costs. Hence, it is very important when planning new district heating areas with low line heat density to evaluate the possibility of achieving large thermal widths. An important factor is of course also the degree of connection, which should be as close as possible to one in order to get good district heating economy.

Both areas in Figure 2.4 have the same size and the same thermal density, but the right area uses the pipes more effectively (i.e. larger thermal width and higher line heat density) and will therefore result in lower network costs and lower heat losses.

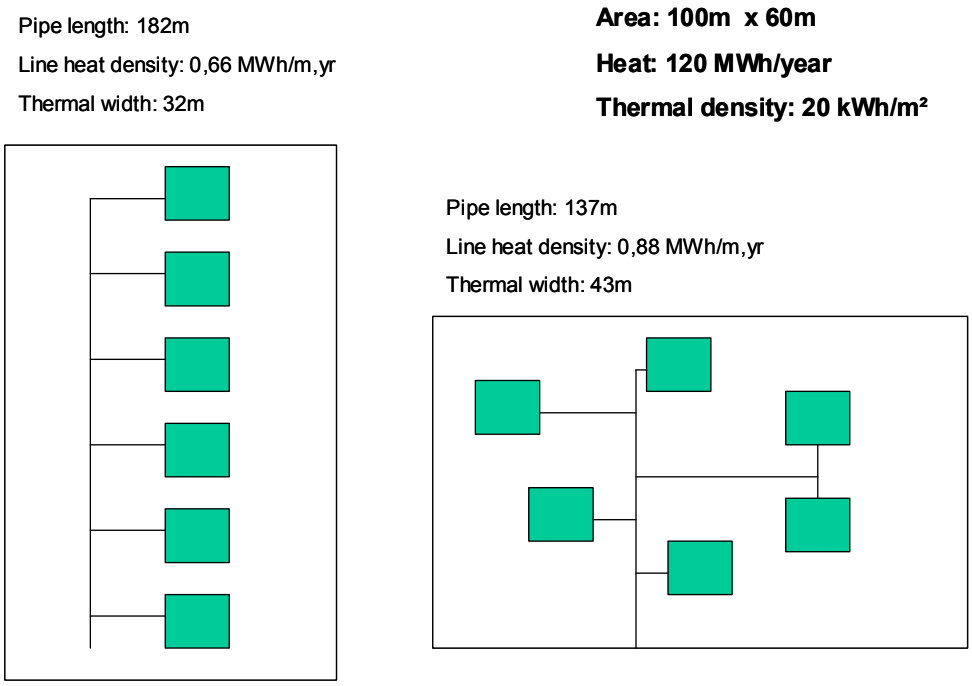


Figure 2.4: Illustration of thermal width for an area of the same size with two different pipe geometries. The thermal density is 20 kWh/m²,yr corresponding to an average size of the property of 1000 m² per customer.

The relationship between heat density and line heat density (for 100 % connection) is shown in Figure 2.5. The diagram shows the results from Larsson et al. (2002) based on an analysis of 27 areas with detached houses in Sweden. Lines with constant thermal width are also indicated. The average thermal width is 35 m with a variation between 72 m and 15 m. The average heat density of the area is 25 kWh/m² which means that the average line heat density is roughly 0.8 MWh/m²,yr, i.e. considerably larger than the lower limit above mentioned by Kristjansson et al. (2004). The areas with the lowest thermal width are rows of houses or rows of houses mixed with tightly placed detached houses.

The lowest line heat densities in the Swedish study are for areas with around 0.35- 0.4 MWh/m,yr, i.e. close to but still above the limit given by Kristjansson et al. (2004). In this report, the average heat line density from 250 projects was around 0.8 MWh/m,yr. Hence this value can be considered as typical for areas with close placing of detached houses as is common in living areas at the borders of cities. District heating areas with line heat densities as low as 0.2 MWh/m,yr are only found in exceptional cases.

2.5 The economic limits of line heat density

In a recent study, Reidhav and Werner investigated the profitability of district heating in areas with low heat demand density for 74 areas belonging to Gothenburg Energy in Sweden (Reidhav, Werner, 2007). In their paper, the following criteria for a successful district heating connection in areas with low heat demand were pointed out:

1) A market situation that allows a competitive district heat price.
2) High use of district heat/house.
3) Low marginal heat generation costs.
4) Low relative heat distribution losses.
5) Low service and maintenance costs.

6) Low demands on rate of return from the owners of the district heating company.
7) Low investment costs per house by means of, for instance, short pipe lengths per house.

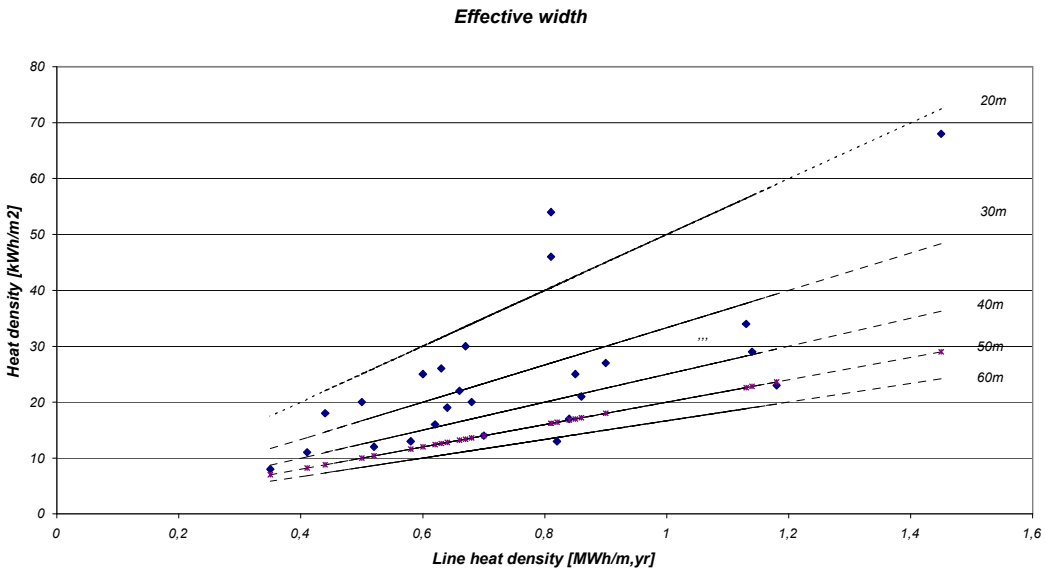


Figure 2.5: Relationship between heat density of an area and line heat density. The deviation of the points from the curves of constant effective width reflects the case that the connection degree is below 100 % (Reidhav, Werner, 2007).

The conditions above might be difficult to fulfil simultaneously, depending on local conditions in different regions and countries. Therefore, it is not possible to give generally valid criteria for the border line between district heating and alternative heating systems. For example, in Sweden the situation with high consumption taxes on oil, natural gas and electricity is favourable for district heating. Energy saving measures are counteracting and the development of new loads in district heating such as dishwashers and washing machines driven by heat are important factors for good DH economy. Of course the work described in this report aimed at lowering the heat distribution costs and the distribution heat losses, is a very important factor in this context.

In Figure 2.6, an example is given for the 72 areas with detached houses in Gothenburg. The net present value (NPV) in €/house is shown as a function of the line heat density for all investigated areas. The net present value includes the revenues (price charged to customer), the investment costs for the new network and the marginal heat production costs (including heat losses), as well as maintenance costs for the situation of Gothenburg Energy. When NPV is negative, the costs for the DH company are higher than the revenues.

The example shows a wide scatter for different areas with a correlation function
NPV = -9800/Lhd + 18400.

The break-even point for the correlation curve corresponds to a line heat density of 0.52 MWh/m,yr. The system with the lowest positive NPV has a line heat density of 0.35 MWh/m,yr. These values are about twice the values given by Kristjansson et al. (2004), which possibly reflects the situation of city areas in Göteborg, which might implicate higher investment costs of district heating networks compared to the average Danish situation.

The main conclusion from the Swedish study is that besides on the line heat density, the profitability depends on the total heat load of the area. Bigger loads result in lower relative heat losses and thus increased profitability. The investment costs represent a considerable proportion of the total supply cost. When maximising the difference between revenues and costs, the focus should be on both low marginal heat generation costs and low heat distribution investment. Low heat generation costs cannot alone offset a high heat distribution investment and vice versa.

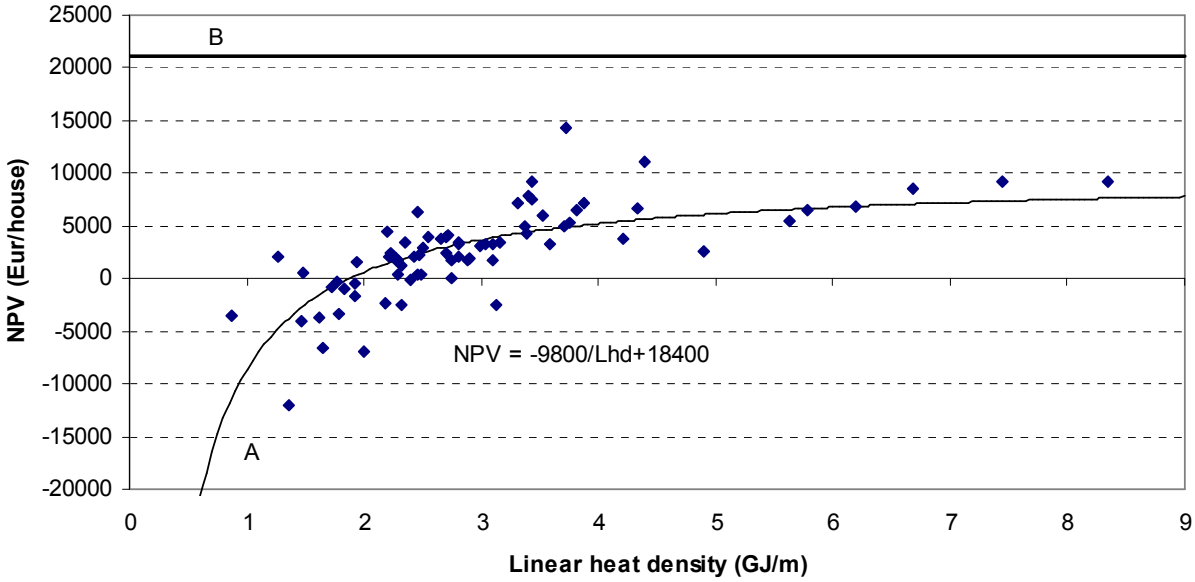


Figure 2.6: The relationship between net present value and heat line density for areas of detached houses connected to district heating in Gothenburg according to Reidhav and Werner, (2007) (Curve A). Line B is the average NPV when only revenues from the average heat delivery per house and the marginal production costs are considered. The difference between the constant value of B (21000 €/house) and the asymptotic value (18400 €/house) is the fixed cost of the customer installation (2600 €/house).

Compared to other countries, the market situation for district heating in areas with low heat demand is more favourable in Sweden due to high energy and carbon dioxide taxes on fuel oil, natural gas, and electricity. Hence, it should be much more difficult to reach low values of still profitable line heat densities in other countries. However, the example of Denmark showed that their work of decreasing the piping costs was very successful.

2.6 Environmental limits for low line heat density

Besides costs, the environmental impact of a heating system is an important question. New heating systems should only be acceptable if they are also suitable in respect to their sustainability. In, Sweden, a special study was devoted to this problem (Fröling, 2004). As in the Danish study described above, district heating with low heat demand density was compared with oil heating in order to figure out in which way decreasing heat line density affects the environment. The investigated customer had an annual heat need of 20 MWh.

In this study, life cycle inventory data for district heating distribution systems in areas with low heat line density has been compared with the use of oil furnaces. The environmental impacts are categorised into Global Warming Potential, Acidification Potential, Eutrofication Potential and Use of Finite Resources. To enhance the assessment, three single point indicators have also been used: EcoIndicator99, EPS and ExternE.

Figure 2.7 shows the result from the model regarding Global Warming Potential. The contribution if using a local oil furnace minus the contribution if using district heating is shown. For line heat densities where the result is larger then zero, district heating is the better alternative. Similar types of graphs are found for the other environmental parameters studied. Different parameters give different results.

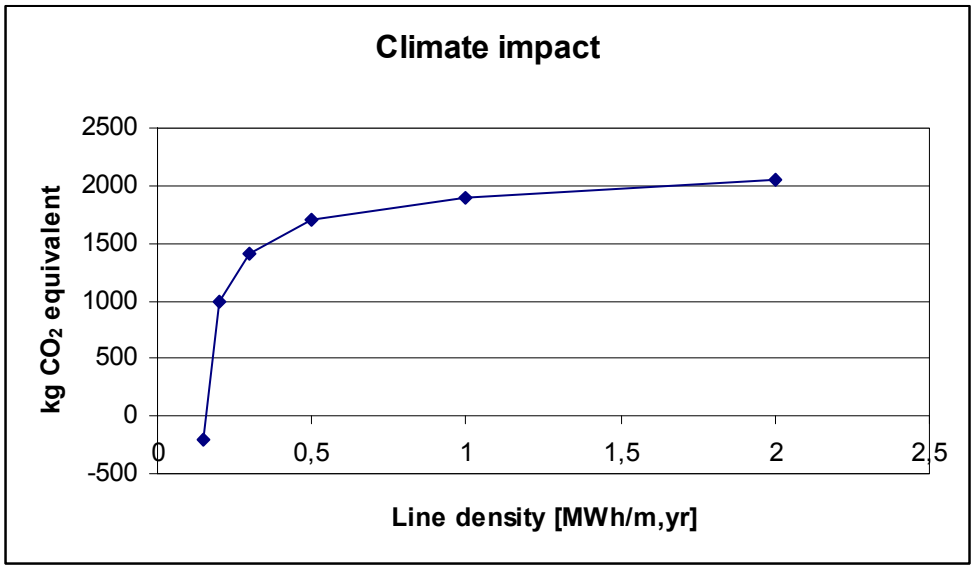


Figure 2.7: The impact of climate emissions in kg CO_2-equivalents as a function of line heat density in comparison with oil heating. (Positive values: emission of oil heating dominates, negative values: emission of district heating dominates, according to Fröling, 2004).

An assessment of all results indicates that with the type of technology used at present it is not environmentally beneficial to use district heating with lower line heat density than 0.2 MWh/m,yr. (This holds for the Swedish heat production mix which includes only 20 % fossil fuels. For district heating systems including a higher amount of fossil fuels, the limit will be positioned at lower line heat densities).

3 Examples of applications with low heat demand

Summary:

This chapter describes examples from sparse district heating applications realised in Sweden, Finland and Denmark. The intention with this chapter is to show how district heating is used in areas with low heat demand density, and which losses and other typical system conditions are prevailing.

3.1 Prästmarken - an area with 103 detached houses in Växjö, Sweden

An area containing 103 individually built detached houses is connected to the district heating network of Växjö Energy AB (Zinko, Bøhm, 2005), the municipality owned district heating company of Växjö (see Figure 3.1). The houses are relatively new, built in the time between 1995 and 2004 and the DH-network was constructed during the same period. Because of the modern building constructions, the annual heat load is relatively low, i.e. about 15000 kWh per house with a total trench length of about 3000 m. This results in a line heat density of about 0.5 MWh/m.yr, which is low with respect to the compact locations of buildings (Figure 3.2). The network consists of 78 % twin pipes and 22 % preinsulated single pipes.

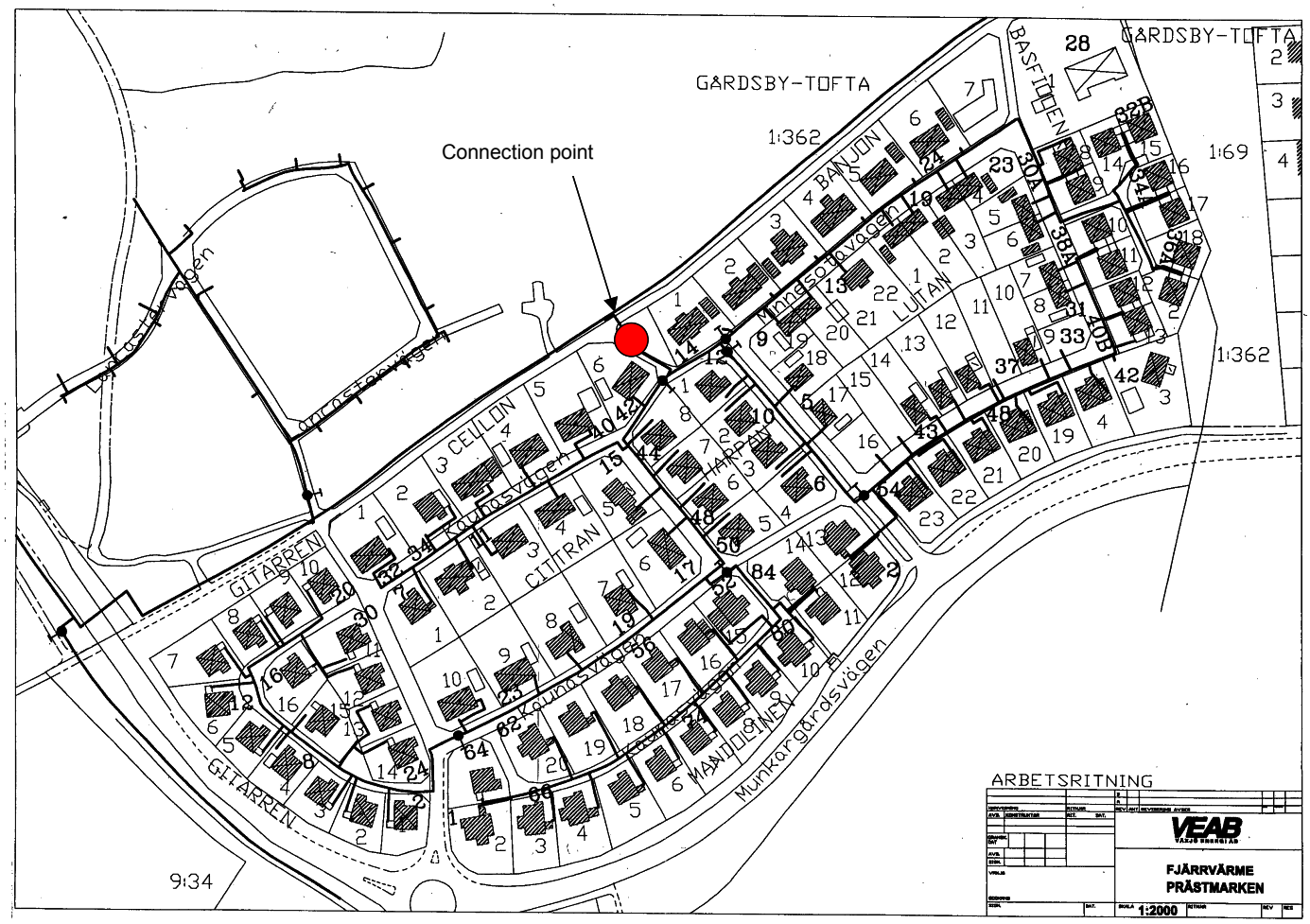


Figure 3.1: Area of detached 103 houses in Växjö, Sweden

The substation for each house is designed in the common Swedish way with two parallel heat exchangers, one for direct water heating, one for the heating circuit (see Figure 3.3). The substation used in most cases is that of Redan. In the course of a research project, the heat supply and the heat loads were analysed for 2004, the measurement method being based on determining the energy difference between the heat delivered to the area and the sum of all energy delivered to the substations of the houses.

Figure 3.2: Modern detached houses with relatively low heat load of Prästmarken, Växjö

The total energy delivered to the area was measured by means of a main meter connected to the distant metering system of VEAB placed in a measurement container together with a data-logger. The measurements of the substations in the houses were undertaken by a remote metering system also connected to VEAB. The difference between the main meter reading and the sum of all substation readings gives the energy loss due to the network. In order to receive reliable results, the measurements were performed in summer time.

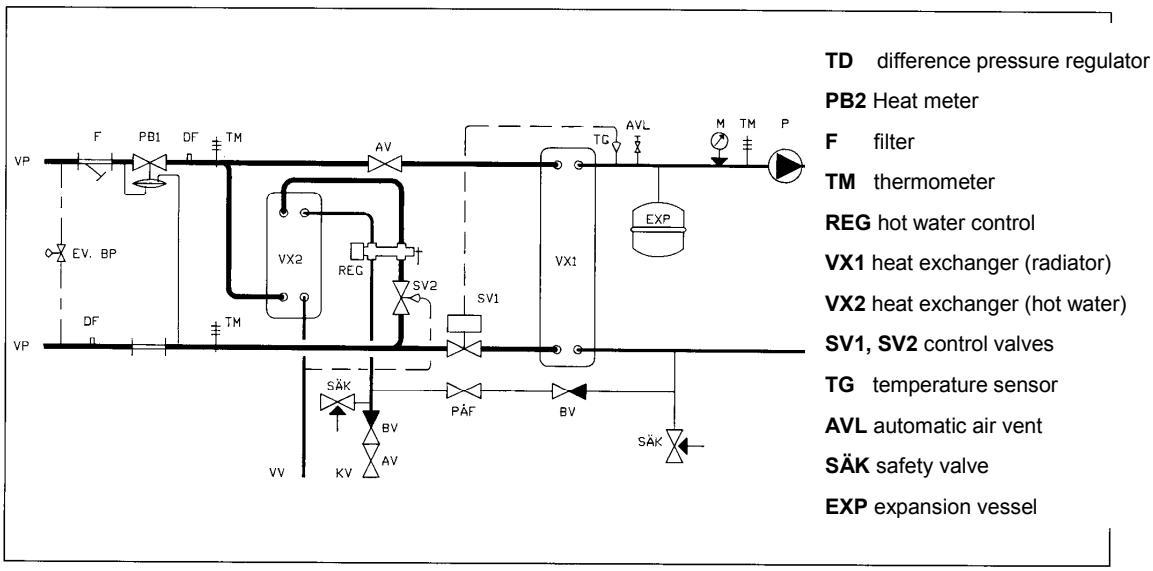


Figure 3.3: Customer substation for detached houses.

The comparison of the theoretical and measured data gives a consistent result, if the ageing of the district heating pipes, especially of the pipes with CO_2 blown insulation foam, installed between 1995 and 1997, are accounted for. The annual heat loss of all pipes, between the time they were new and July 2004, has increased by 8 %. In spite of that, the total annual heat loss of the local network for season 2003/2004 was only 19 % of the total energy delivered to the area (or 24 % of the energy delivered to the houses). In absolute figures, the annual heat loss is 363 MWh or 14.9 W/m. In July, the heat loss is about 40 % of totally delivered energy. This is considered to be a relatively low amount of heat loss (absolutely and relatively) compared to that usually seen for such types of housing areas.

An important finding is the relatively large drop of temperature in the network in summer time. This is mostly due to the low summer load. The mean temperature of the network is about 6-7°C lower than the mean temperature of the network at the entrance to the area (at the measurement

container). In some substations, at the end of the branches, the temperature can be well below 50°C in spite of coming in at 75°C to the area. This is a general problem in modern housing areas and has to be solved by temperature-controlled bypasses.

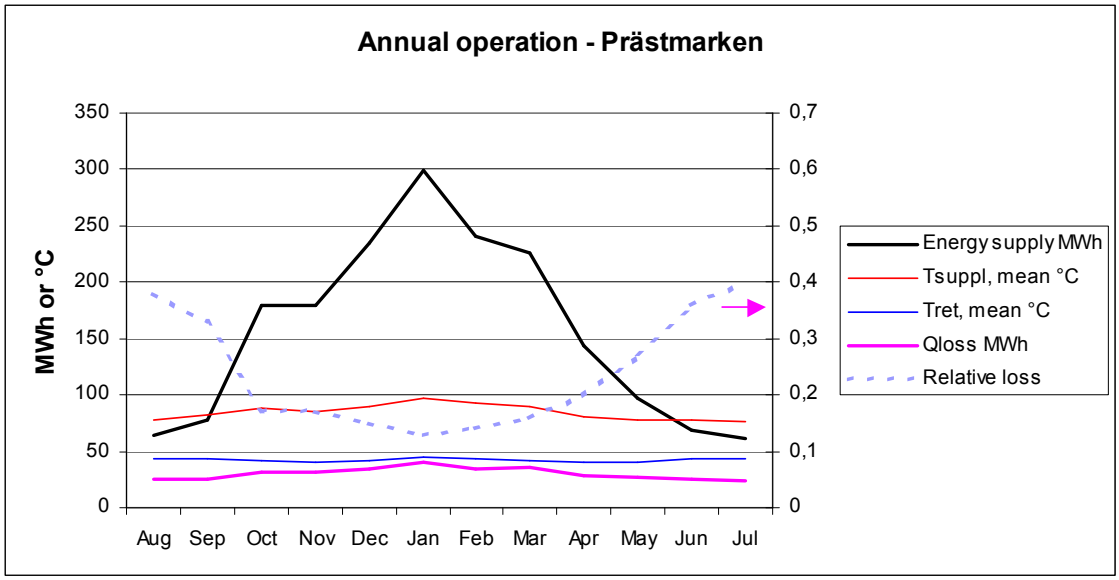


Figure 3.4: Operational parameters of Prästmarken district heating.

Figure 3.4 shows the monthly loads, illustrating the large differences between summer and winter loads. Thus, larger summer loads would be preferable in such a situation.

3.2 Munksundet – an area with 44 link-attached houses in Enköping, Sweden

The Munksundet area is a very tightly built area with detached houses (often the same type) separated by only a garage from each other (Cederborg, Nordgren, 2005). The houses were built in the 1970s with the standard for electrical heating of this time. In 1997, the electrical heating was replaced by hydronic radiators and all the area was connected to district heating, see Figure 3.5.

District heating is delivered to a local substation in the area from which heat is distributed in a secondary network to the buildings. Inside each house, Redan-substations deliver heat for radiator heating and hot water to the customers. See Figure 3.6 for the principal scheme. The pipes are twin pipes in PEX (Wirsbo Ecoflex) installed in house-to-house-connections, i.e. the pipes are mostly drawn through the gardens from one house to the next house. The hot water is supplied via a plate heat exchanger, and heat is provided directly. The Redan-substation is pressure controlled and prioritises hot water preparation. The secondary design temperature is 70/40°C.

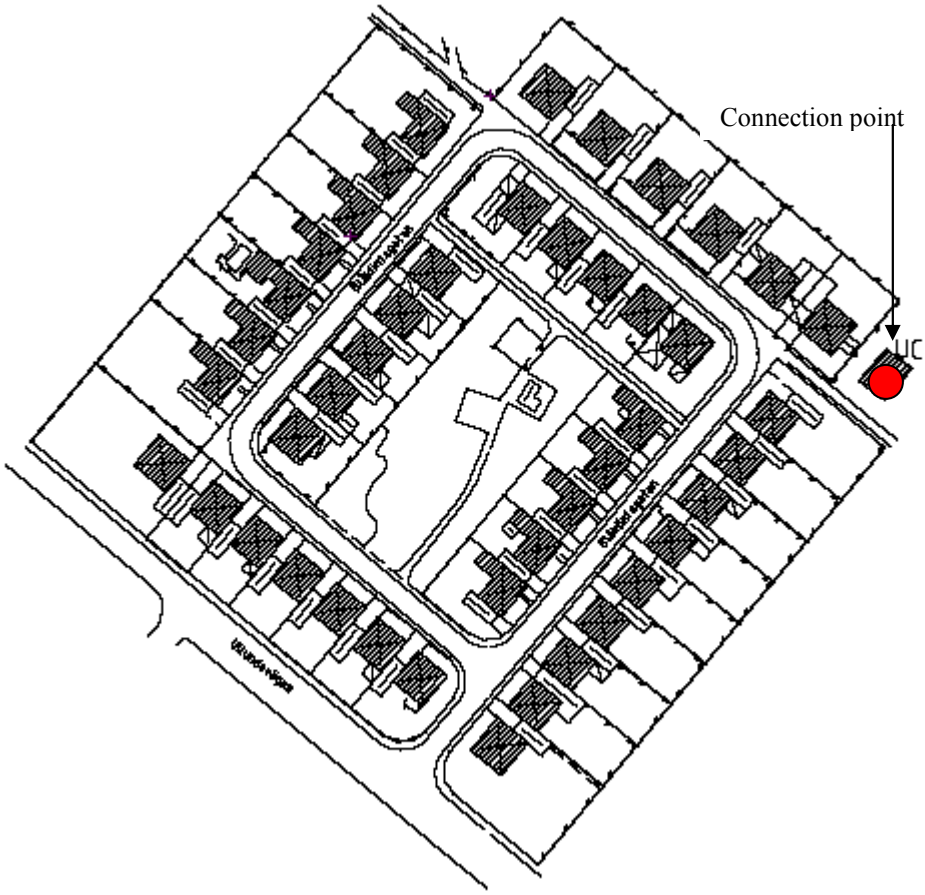
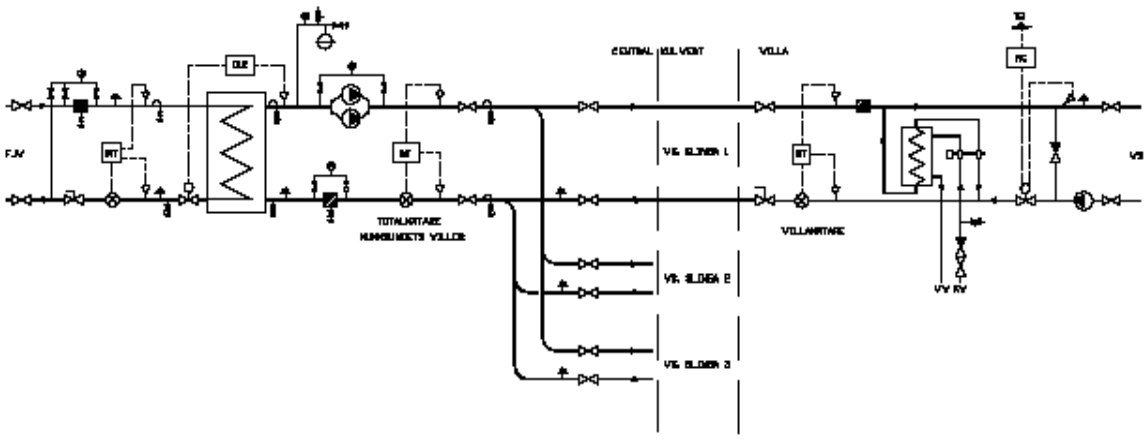


Figure 3.5: The Munksundet area with 44 link-attached houses fed by district heating

The total trench length of Munksundet is 910 meters, distributed over 3 circuits. In these house-to-house-connections, there is no distinction between distribution and service pipes. Branching is done in a service box outside each house. The total annual sum of house loads is 740 MWh, hence the line heat density is 0.84 MWh/m,yr. The corresponding thermal density was calculated to be 24.5 kWh/m². Thus - for areas with detached houses - relatively high line heat density is achieved due to the house-to-house-connection resulting in lower pipe length per house and due to the high building density. The average pipe dimension is 32 mm (inner diameter 26.5 mm).



Figur 3.6: The district heating connection of the link-attached houses in Munksundet.

The heat losses were measured in a similar way as was done in the other projects: Individual heat loads were registered for each house and compared with a heat meter measuring the energy delivered to the total area. The difference of both sets of measurements gives the total heat losses. These heat losses are a combination of heat losses from the pipes to the surroundings and of unregistered flow. The latter occurs in the case of small leakage flow from the Redan-substations, which include thermal bypass valves, which can deliver low flows not detected by the individual heat meters. On an annual basis, these unregistered flows sum up to 3900 m³ of the total 24600 m³

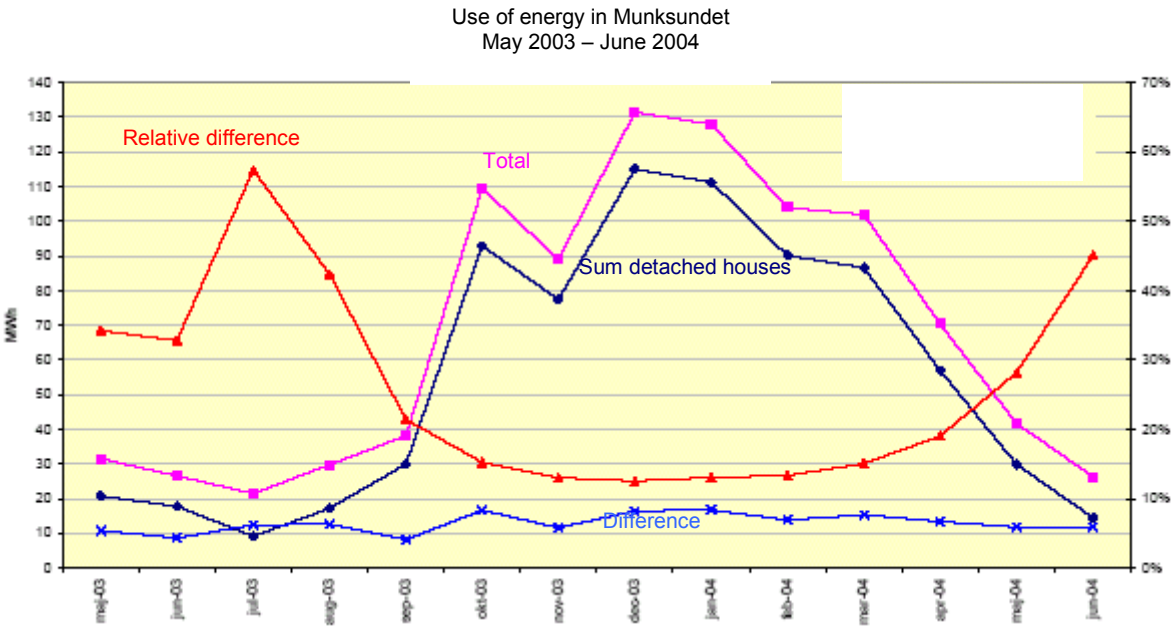


Figure 3.7: Heat use in the residential area Munksundet. The relative deviation between heat load and heat supply can be larger than 50 % in summer time, but is around 18 % for the whole year. The lines show from the top (wintertime): Total meter, sum houses, relative deviation (losses) and absolute deviation (losses).

or 15.9 %. In Figure 3.7, the heat use for one year (May 2003 – June 2004) is shown. A comparison of the theoretical heat losses of the pipes and the measured losses results in an annual direct heat loss of 78 MWh or 10.5 % of the load. This corresponds to a pipeline loss of 9.8 W/m. This is a relatively low value, mainly due to the low annual system temperature. However, the total heat loss including leak flows is 160 MWh or 22 % of house loads, i.e. 17.7 % of the total energy supplied to the area.

The main conclusion from this project is that the relatively low pipe length results in low pipe heat losses. However, differently to Prästmarken, where large temperature drops along the service pipes were found, a relatively high leakage flow was applied for keeping the pipes warm at all times, resulting in an appreciable and normally unregistered load leakage of the same size as the pipe heat losses.

3.3 Rotskär, an area with mixed detached houses with a connection rate of 76 %

In this area, 63 out of 83 houses are connected to district heating (Cederborg, Nordgren, 2005). The houses represent a mixture of different building types and sizes built in the 1960's with individual floor areas between 100 and 200 m² living area per house (Figure 3.8). District heating was introduced 2002 to the area. 76 % of the house owners accepted the offered connection to district heating when the original heating system became out of date. The main distribution pipes are preinsulated steel pipes installed in the streets and service pipes are copper flex pipes in twin design. The mean pipe diameter is DN 40 (including service pipes).

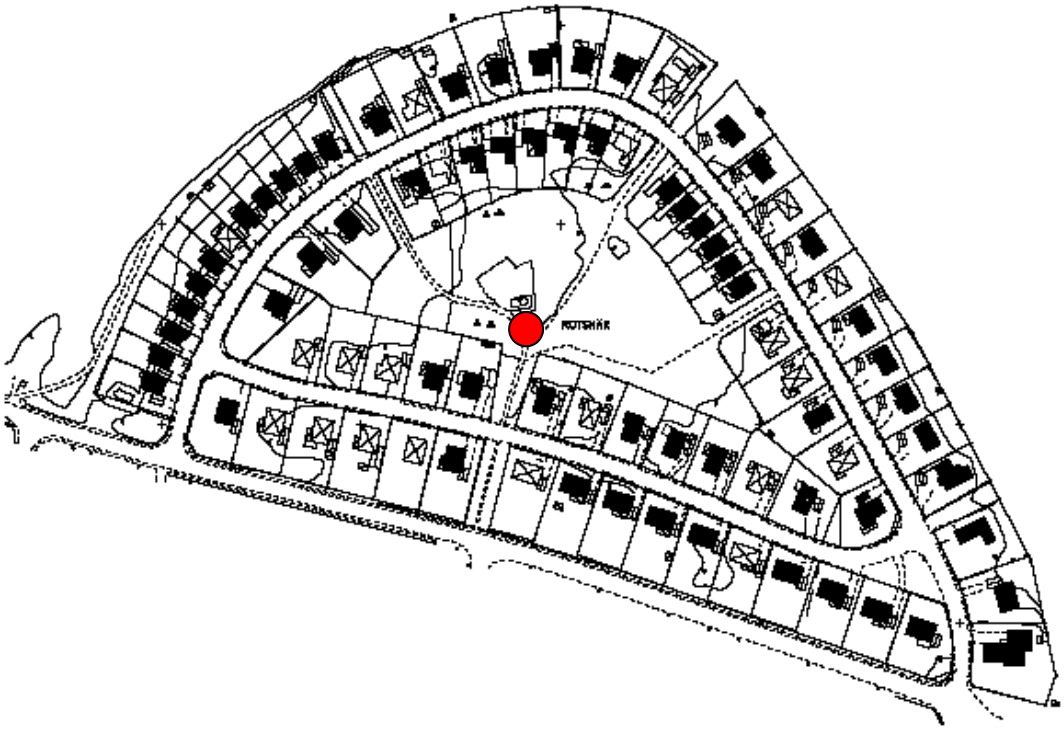


Figure 3.8: Housing area in Rotskär with 83 detached houses, of which 63 are connected to district heating.

The substation is a prefab design with two heat exchangers, the design temperature for the district heating network is 100°C and for the house side 80°C (Figure 3.9). The local distribution network is connected to one point at the local school from which the local distribution network is drawn. At this point, also a main meter for heat balance measurements was installed.

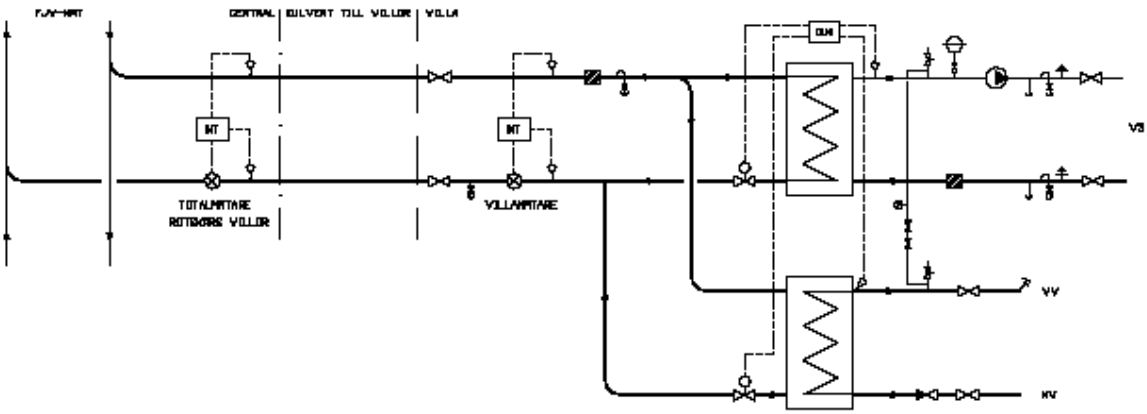


Figure 3.9: The district heating connection in Rotskär. Heat is transferred to the house by a district heating substation for heating and hot water. Each house has a heat energy meter. The supplier is able to collect data from the meter for invoicing by remote access.

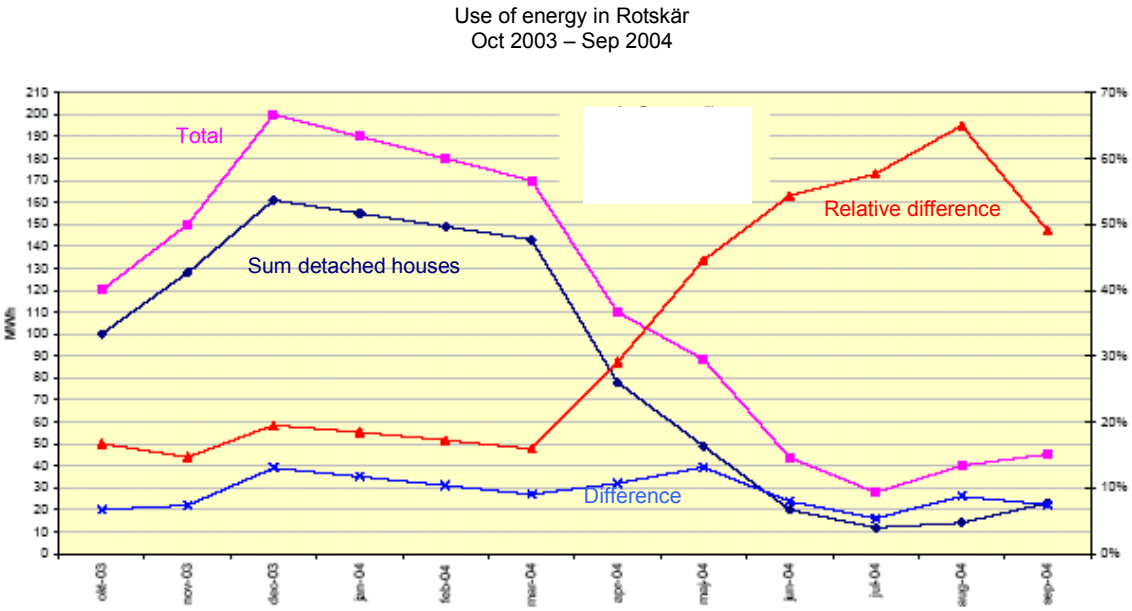


Figure 3.10: Heat use in the residential area of Rotskär. The difference between the main meter and the house meters corresponds to heat losses and measurement losses. The deviation increases (per cent) during summer season. The deviation is about 15-20 % during heating season. The deviation varies between 20-40 MWh (monthly mean value).

The total trench length in Rotskär is 2100 m, of which 1000 m are service pipes. The annual load is 1030 MWh, hence the line heat density is 0.49 MWh/m,yr, i.e. the same as in Prästmarken. The average annual house load is only 13 MWh, which means that the buildings must be reasonably well insulated. Due to the disparate location of the buildings, the heat density of the area is only 8.3 kWh/m². The total heat losses (both pipe heat loss and unregistered flow similar to the analysis in Munksundet) were determined to be 330 MWh (Figure 3.10). This is equal to 32 % of the summed house heat loads or 24.3 % of the total heat supplied to the area. The mean pipe heat loss was 12.5 W/m, i.e. 30 % higher than in Munksundet due to the higher system temperatures. However, they are lower than measured in Prästmarken, probably because a small, unregistered leakage flow also occurs in Prästmarken, which is included in the heat loss value.

3.4 Examples of applications with low heat demand, Denmark

In Denmark, the district heating community has been much concerned with the new design loads in the Danish Building Code, effective 2006, and their effect on the design and operation of DH systems.

For "normal" dwellings the maximum heat demand ("energy frame") is:

- 70 + 2200/(heated floor area) ≈ 87 kWh/m^2,yr
- or 11.3 MWh per year for a 130 m^2 house.

For Class 1 low energy buildings, the energy frame is half the above value. Further reductions of the heat demand are anticipated in 2010 and 2015.

The energy frame includes all energy needed to heat the building, i.e. electricity for pumps, ventilation and internal losses, besides space heating and domestic hot water. Electricity consumption (for pumps and fans) is weighed by a factor of 2.5. Renewable Energy Sources can be used without affecting the energy frame.

With an estimated length of service pipe and parts of the distribution network of 30-40 m per house, the line heat density will be 0.3-0.4 MWh/m,yr in the present situation, and half of this value in 2015.

The role of district heating in the future energy supply system in Denmark has been much debated by the district heating community, among others. In the report (Ramboll, 2006), the economics of DH supply was compared with individual heating for a hypothetical area in Støvring, Jutland. The new built area shown in Figure 3.11 was also designed for different DH system solutions.

The following alternative DH system designs were analysed:

- Hot water tanks or hot water heat exchangers in the buildings
- Single pipes or twin pipes
- Available differential pressure to the housing area high (400 kPa) or low (200 kPa)
- Constant or varying supply temperature 60-80°C
- Normal lay-out of pipes, or with some pipes laid inside the building envelope
- 100 % or 80 % of the buildings connected
- Use of supplementary RES.

The layout shown in Figure 3.11 is advantageous for DH supply, because it results in only a few meters of pipe per house. In this case, the line heat demand is approximately 0.37 MWh/m,yr, slightly dependent on the system solution.

Of the different DH system solutions, the following system is one of the most favourable: *Twin pipe system with hot water tanks, available differential pressure 200 kPa, all buildings connected:*

- Average heat demand per building: 5.6 kW, or 12.2 MWh per year.
- Length and dimension of service pipe per building: 15 m DN16.
- Length of network per building: 33.0 m.
- Annual efficiency: 0.81.

Investment in network per building: 3220 EUR which is very low compared with the Peter Freuchenvej case: 5590 EUR, cf. Section 8.2.

Compared with the present work it should be noted that the assumptions in Ramboll (2006) are very simple and can be argued.

- The return temperature from the hot water tank and the hot water heat exchanger are assumed equal. The return temperature from space heating and hot water systems is 40°C in the design case. This means that a hot water tank and a plate heat exchanger has the same influence on the return temperature from the building, but of course not on the heat demands and flows.
- Annual operational costs are calculated from the design case and an estimated annual temperature difference for the heat losses and an estimated maximum operation hours for the circulation pump.

As will be shown in Section 8.2, we find in this work that the Hot Water Heat Exchanger can result in a lower Net Present Value than solutions based on a Hot Water Tank.

Figure 3.11: Layout of DH system in Støvring: Traditional development areas with low heat density (detached houses) in combination with some buildings with higher heat density (semi detached houses – blue areas).

4 Evaluation of loads in district heating systems with low heat demand density

Summary:

This chapter describes evaluation results of two systems with low heat demand density: Neidonkallio near Espoo in Finland and Peter Freuchenvej in Nykøbing/Falster in Denmark. The purpose of this chapter is to give some examples about typical operational conditions in these systems and also to illustrate the use of different system solutions. In Neidonkallio, the energy for space heating is delivered via substations with two heat exchangers in parallel, one for space heating and one for hot water preparation. In the Peter Freuchenvej-system, this solution is also used in some buildings, whereas the majority of the buildings have direct-connected radiators and a hot water storage tank fed by district heating. In the Finnish example, the measurements are also compared with results from a simulation model.

4.1 Neidonkallio

4.1.1 The system

Neidonkallio small house area is located about 30 km West of Helsinki in Kirkkonummi area. Neidonkallio and Kirkkonummi are part of the DH-system of Fortum Ltd. in Espoo. The buildings are quite new, built in 2004 – 2007.

- 28 small houses, 3 row houses in 2006
- building volume 53 225 m^3, 14 028 m^2
- connected capacity 900 kW, connected with heat exchangers
- load density 410 W/m DH-line, line heat density: 1,4 MWh/m,yr.

Neidonkallio DH-system is built like a typical new pipeline system in Finland. Pipes are made of polyurethane foam insulated steel pipes with plastic jacket. The total length of the DH-line is 2.5 km. The amount of wells and valves has been minimized. There is no separate pump for the area. The system uses the pump capacity of the line from Suomenoja CHP-plant to Kirkkonummi. The main characteristics of the Neidonkallio system are:

- 2-pipe system
- normal outgoing temperatures 115/75°C (winter/summer)
- return temperature 30 - 50°C
- DH-line total 2500 m: transport line 334 m, delivering line1429 m, service line 738 m.

The DH- pipeline system at Neidonkallio area is shown in Figure 4.1.1.

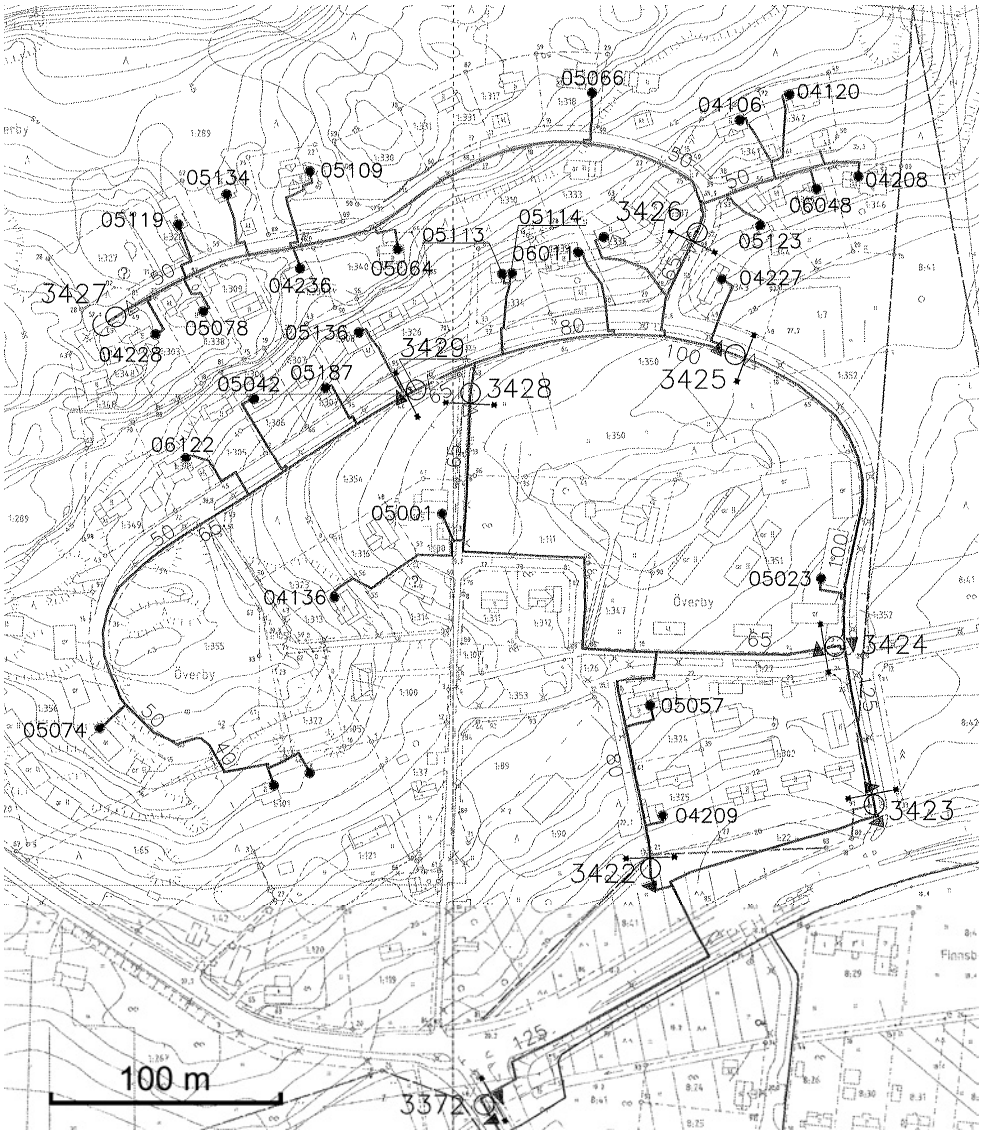


Figure 4.1.1: DH-pipeline system at Neidonkallio area.

A view of the houses in the analyzed Neidonkallio area is shown in Figure 4.1.2.

Figure 4.1.2: Typical view of Neidonkallio area

The typical solution for the customer substation is shown in Figure 4.1.3.

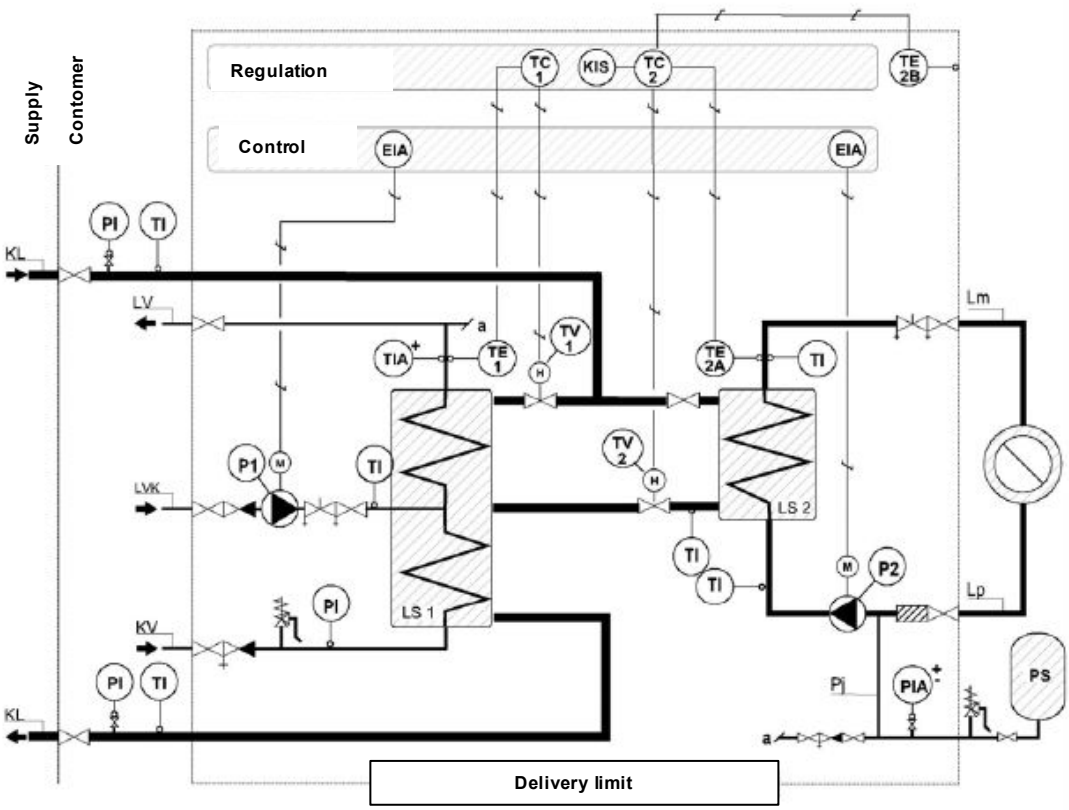


Figure 4.1.3: Customer substation in Neidonkallio

4.1.2 Measurements

Measurements were collected from all 31 customers in Neidonkallio area connected to the district heating network. All measurement data contain time stamped values for supply and return temperatures (ºC), cumulative energy (MWh) and volume (m^3), average heat demand (kW) and flow rate (m^3/h). Measurement data from 18 customers was saved hourly and from 13 customers

five to six times a month. Additionally, measurements from one 17-apartment group of row houses were also saved as one-minute values.

The measurements started in the beginning of summer 2005, the first one on May 21st. Figure 4.1.4 below illustrates the measurement period for each measurement point as well as the type of measurement.

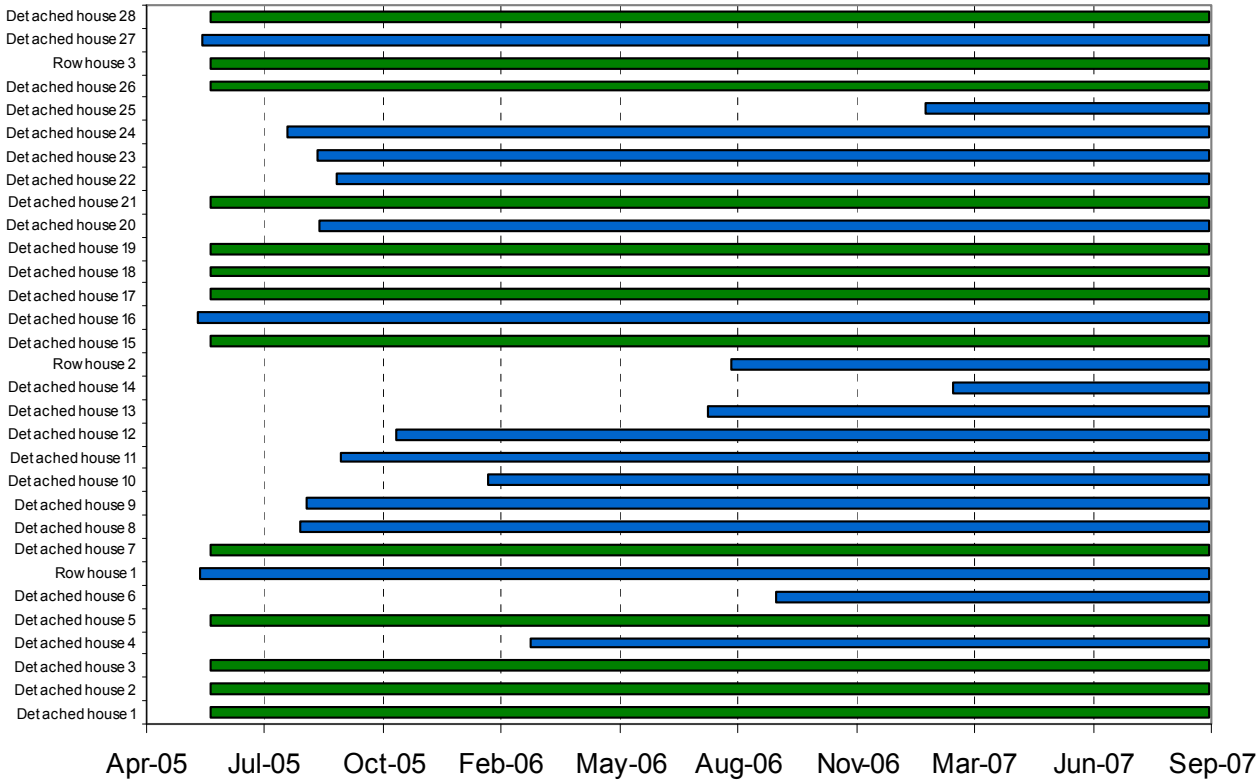


Figure 4.1.4: Measurement periods and types for every customer in the Neidonkallio area.

Caption: Green bars indicate measurements with values recorded 4-5 times per month; dark blue bars indicate hourly measurements.

The following figures present some examples of the collected measurement data.

Figures 4.1.5 and 4.1.6 show the yearly energy consumptions (MWh) and the specific consumptions (kW/m^3) of all customers in Neidonkallio area in 2006. The total annual consumption was about 1.8 GWh. The row houses are connected via one DH-substation supplying heat to a larger number of customers (15 – 20) per substation.

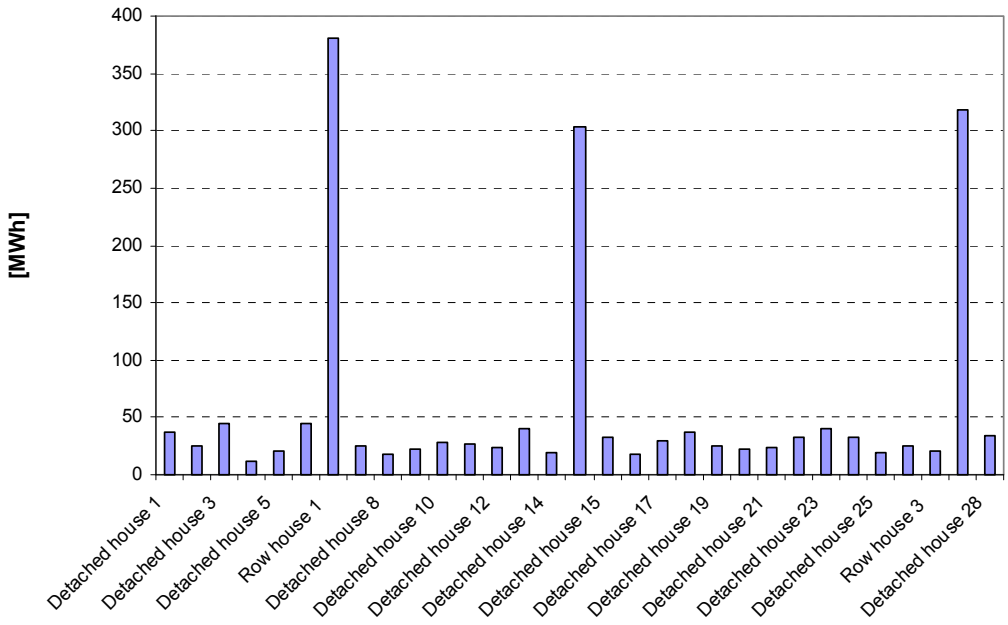


Figure 4.1.5: Energy consumptions of customers in Neidonkallio, 2006.

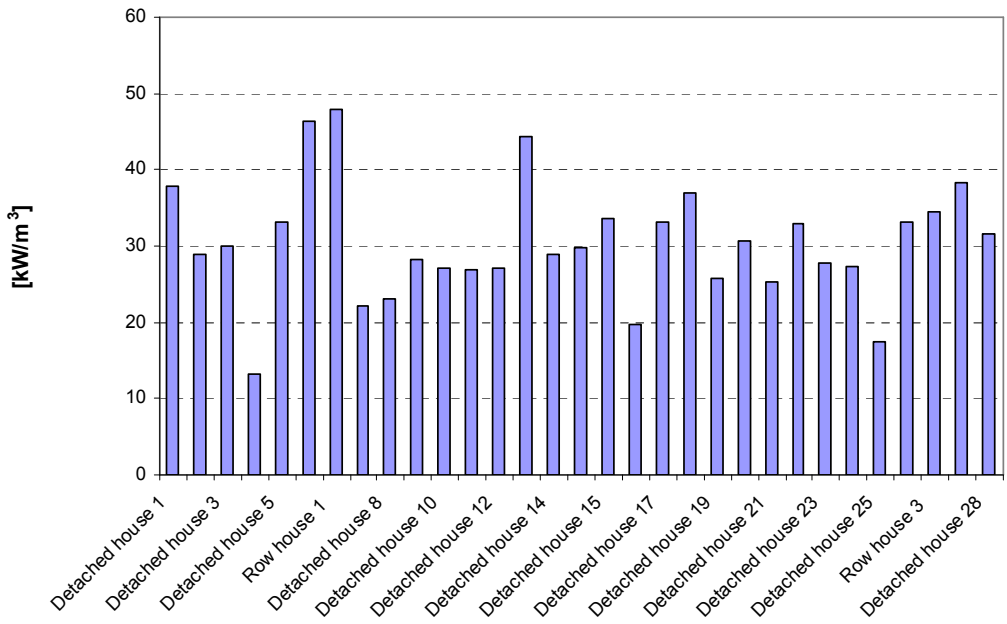


Figure 4.1.6: Specific consumptions of customers in Neidonkallio, 2006.

Figure 4.1.7 represents a typical one-week heat demand profile in summer and wintertime respectively, for a detached house in Neidonkallio. Figure 4.1.8 shows the same for a row house based on one-minute data. Both one-minutes load values and hourly loads are shown. Both figures also include outdoor temperature for the winter period.

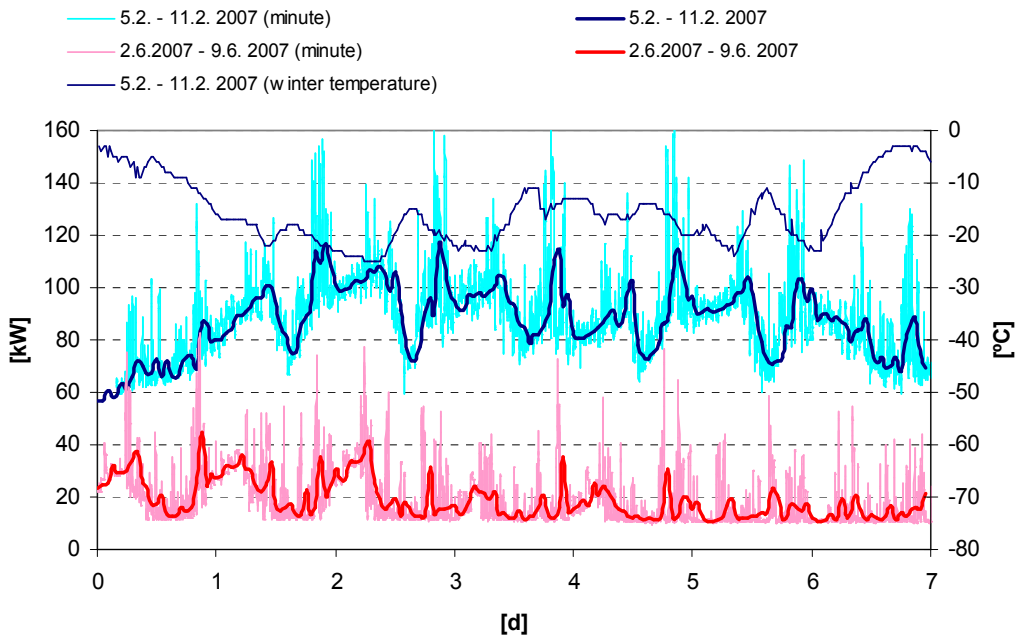


Figure 4.1.7: Heat demand profile for a detached house in summer and wintertime, hour and minute measurement data.

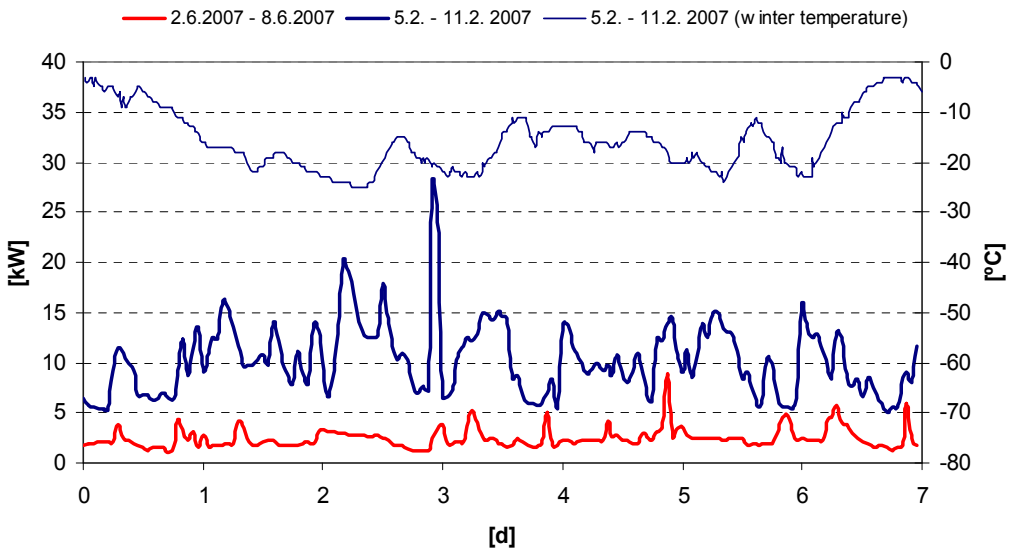


Figure 4.1.8: Heat demand profile for a row house in summer and winter.

Before making any generalizations of results in figures 4.1.7 and 4.1.8 above, it must be noted that figures represent individual customers and especially in the case of detached houses, the building characteristics and personal habits have a significant influence on results.

4.1.3 District heating network model

A district heating network model was used to study the operation of Neidonkallio network (Figure 4.1.9). The model handles the network as nodes and pipes between nodes. Nodes are defined as producers, customers or simply connecting nodes between pipes. According to their task, nodes are provided with different sets of needed input data as time series. Pipes have attributes such as length, diameter and heat loss coefficients, as well as information on start and end nodes.

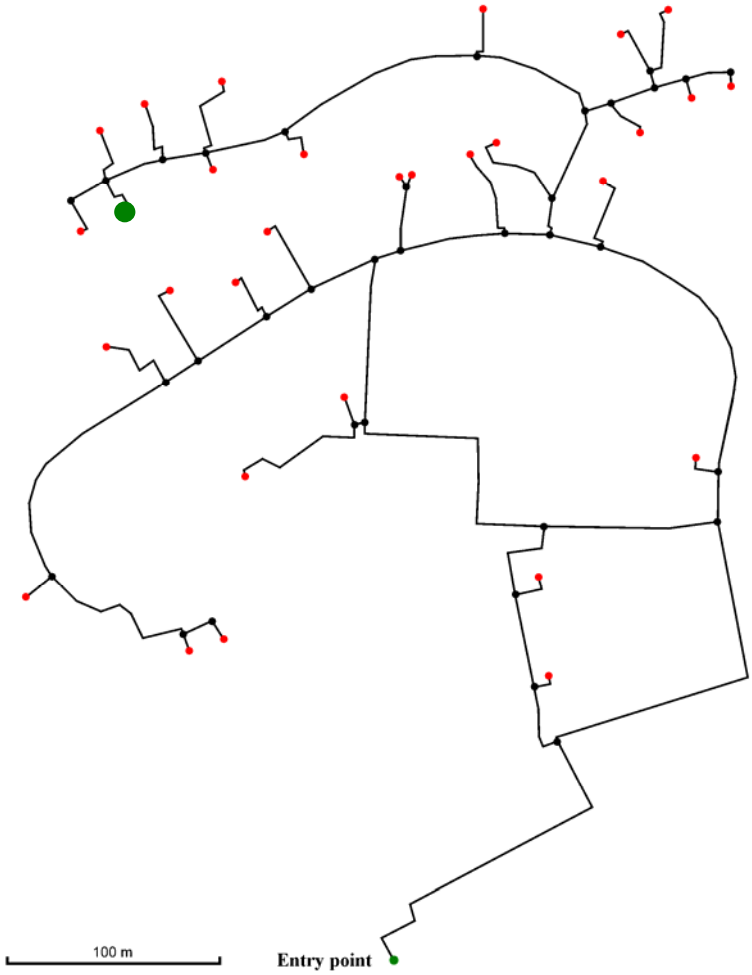


Figure 4.1.9: Neidonkallio network as modelled in district heating network model, red dots marking the customers and black dots the connecting nodes. The entry point of the network is marked as a green dot.

Input data needed by the model are heat demands and temperature differences of customers and supply temperature at the entry point of the network. Customer specific heat demands and temperature differences were provided as time series using the measurement data. The supply temperature of the entry point was approximated using measurement data of the nearest customer. Additionally, the model needs a value for undisturbed ground temperature to calculate heat losses and temperature drop in pipes. This was set to be 5ºC, which is a value generally used for average ground temperature in Finland.

As a result, the model calculates flows, pressures, temperatures, pipe specific heat losses and the total pumping power in the network for the simulation period.

The simulation period was decided to be February 2007, because it was the month with highest heat demand in the period where measurement data from all the customers was available. As an introduction, Figure 4.1.10 presents the heat demand of Neidonkallio area along with temperature difference between indoor and outdoor temperatures.

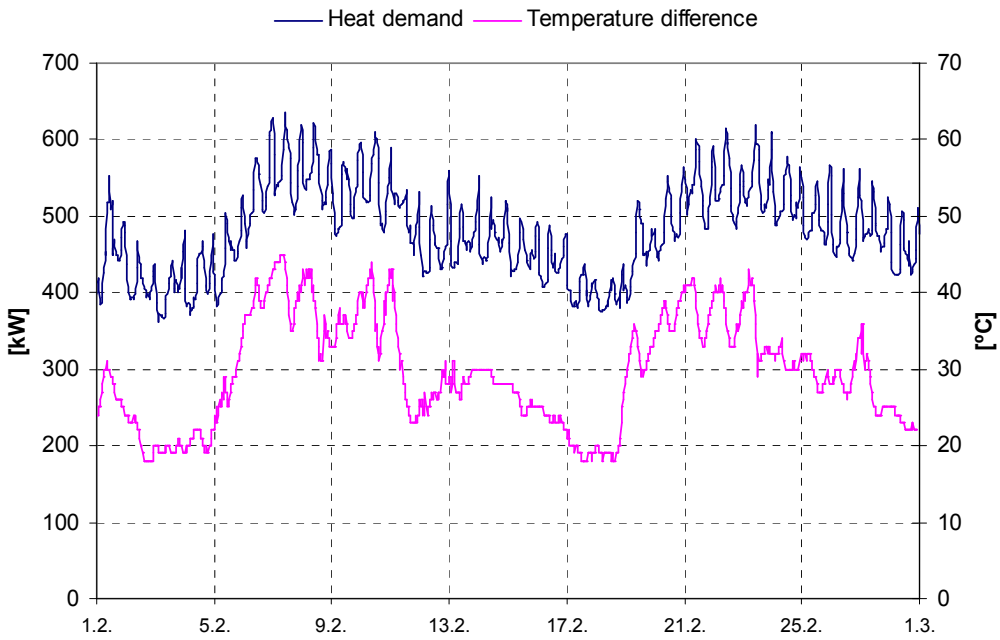


Figure 4.1.10: Heat demand and temperature difference between indoor (20ºC) and outdoor temperatures in Neidonkallio area, February 2007.

The model uses pre-calculated values of pipe size and specific heat conductance per length (Table 4.1.1) to calculate heat losses. When calculating the conductance, heat conductivity values used for insulation and ground were 0.027 W/mK and 1.6 W/mK, respectively. Installation depth was 0.5 m and both supply and return pipes were assumed to be on the same horizontal level.

Table 4.1.1: Pipe size specific U-values (W/(mK)) used in calculation of heat losses.

	Single pipes (U_1)			Twin pipes (U_1)	Single pipes (U_2)			Twin pipes (U_2)
Size	**Series 3**	**Series 2**	**Series 1**	**-**	**Series 3**	**Series 2**	**Series 1**	**-**
DN 15	0.0958	0.1036	0.1189	0.1563	0.0012	0.0015	0.0021	0.0424
DN 20	0.1104	0.1208	0.1421	0.1611	0.0016	0.0020	0.0029	0.0503
DN 25	0.1294	0.1439	0.1752	0.1573	0.0023	0.0029	0.0045	0.0499
DN 32	0.1415	0.1568	0.1788	0.1746	0.0026	0.0033	0.0045	0.0576
DN 40	0.1588	0.1783	0.2072	0.2037	0.0033	0.0043	0.0060	0.0612
DN 50	0.1726	0.2005	0.2326	0.2045	0.0037	0.0053	0.0073	0.0683
DN 65	0.1949	0.2261	0.2767	0.2419	0.0046	0.0064	0.0100	0.0766
DN 80	0.2069	0.2373	0.2852	0.2651	0.0045	0.0062	0.0092	0.0722
DN 100	0.2150	0.2475	0.2984	0.2757	0.0045	0.0062	0.0094	0.0825
DN 125	0.2425	0.2884	0.3501	0.2589	0.0054	0.0080	0.0123	0.0838

Alternative network solutions were investigated using this district heating network model. Results from these analyses are described in chapter 8.

4.2 Peter Freuchenvej, Nykøbing/Falster, Denmark

4.2.1 The system

The district heating area at Peter Freuchenvej is part of the Nykøbing/Falster DH network, and is shown in Figure 4.2.1.

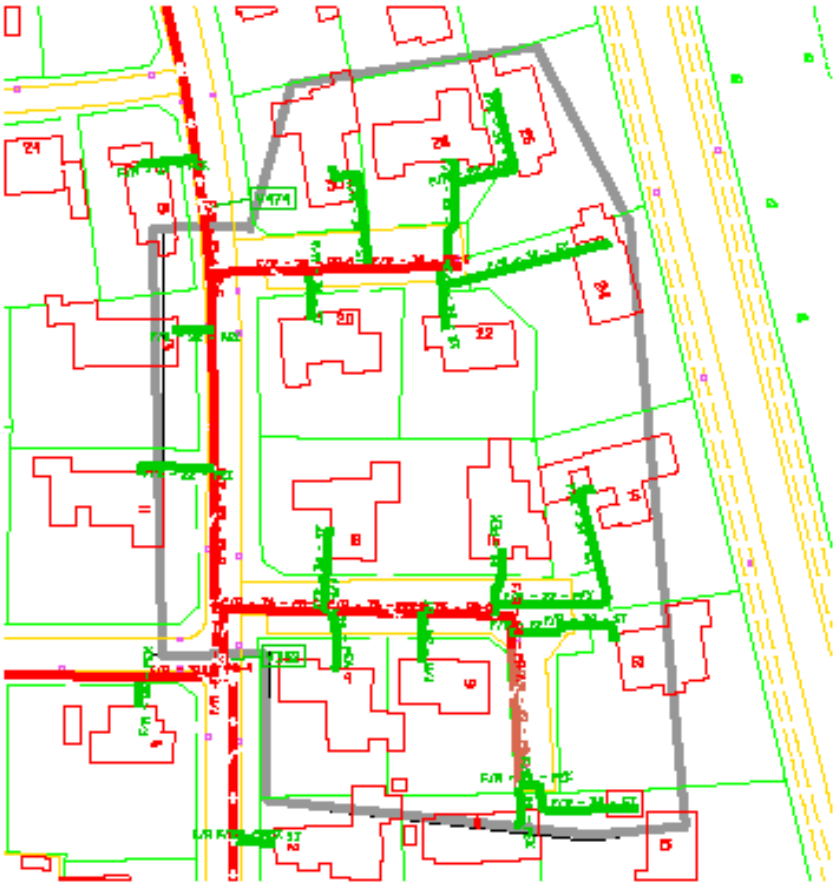


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Figure 4.2.1: The Peter Freuchenvej area. Network layout 2005.

It consists of 16 buildings, supplied from the North by a small shunt arrangement, see Figure 4.2.2. There is an outlet from the area to the South, but the valve is usually closed and has been so during the present investigation. The trench length of the area is 574 m, the heat line density is 0.56 MWh/m,yr.

The buildings were originally built in the late 1960s. Table 4.2.1 shows basic information about the buildings and their heating system.

Figure 4.2.2: The shunt installation at Freuchenvej.

Table 4.2.1: Data for the buildings on Peter Freuchenvej.

Number	**Year of Construc-tion**	**Size** m^2	**Heating installation**	**Yearly consump-tion kWh**	**Annual cooling** °C	**Radiator capacity** W	***Estimated Design Heat Loss*** **kW**
1	1966	180		22 525	45	18 732	7.8
2	1966	143	Air+HWT	15 159	17.2	13 956	4.8
3	1967	189	Air+indirect	17 607	27.5	13 956	5.8
4	1968	184		39 718	32.7	12 405	15.0
5	1966	184		23 964	30.6	19 643	8.4
6	?	229		33 670	40.8	?	12.5
7	1967	165	HWT	9 150	38.9	27 656	2.3
8	1967	179		12 480	35	20 423	3.7
9	1966	189		30 930	47.1	22 451	11.3
10	1970	148	Air+HWT	15 629	47.3	10 905	5.0
11	1966	154		16 235	42.6	15 757	5.2
12	1967	122		12 135	32	10 398	4.5
13	1966	117	HWT	14 770	33.8	12 068	4.6
14	1967	136	Air	16 000	27.5	16 282	5.1
15	1966	180		26 497	37.9	21 593	9.5
16	1967	183	HWT	17 472	28.7	19 614	5.7
Average				**20 246**			**7.0**

The standard installation is a directly connected space heating system (radiators and/or floor heating) and a hot water heat exchanger (Figure 4.2.3). There is one indirect radiator system and four systems with air heating. There are five hot water tanks (HWT).

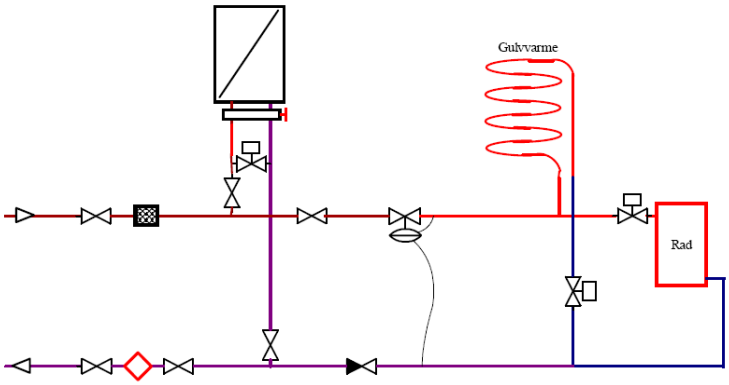

Figure 4.2.3: Schematic of heating installation with hot water heat exchanger and directly connected radiator and floor heating system. Building #12.

In 2006, the old network made of single preinsulated pipes was renovated. Instead, Logstor designed a twin pipe system according to specifications from the municipality. At the same time, the heat meters in the buildings were replaced by ultrasonic heat meters from Kamstrup (Multical 66). The heat meters were ordered in a test version for higher accuracy. Thus, the integration of the energy pulses occurs more frequent than normal in order to achieve good measurement quality when tapping of domestic hot water takes place in the buildings.

The heat meters were connected to GSM data loggers (FA-9 from C.B. Svendsen) and data were collected and sent to a remote PC every night or every week, depending on the time resolution. Usually data were sampled every 5 minutes or every hour.

At the entrance to the area, a shunt arrangement was built (Figure 4.2.2), allowing the supply temperature to the area to be lowered. A heat meter and an electricity meter were installed and connected to a GSM data logger so that the amount of energy, flow and temperatures could be monitored as well as the power consumption of the circulation pump. In order to make accurate heat loss measurements, the undisturbed soil temperature was measured nearby.

4.2.2 Design load of the buildings

According to the Danish Building Code, direct space heating systems should be designed for a supply temperature of 70°C and a maximum return temperature of 40°C at design condition -12°C. In case of an indirect connection (heat exchanger HWHEX), the performance of the heat exchanger must be taken into consideration. Hot water heaters HWTs are designed for summer conditions 60/40°C.

The load from tapping of hot domestic water is specified in Danish Standards. The return temperature from the water heater will depend on the heat transfer area, either the area of the heat exchanger or the area of the heating coil in the hot water tank.

Furthermore, the control of the water heater determines the return temperature, both during tapping and when the water heater is idle. If preference is given to hot water tapping, the space-heating load can be limited while tapping takes place. We will assume a total load of 32 kW in case of HWHEX and 10 kW in case of a HWT.

Recently, models and assumption have been described in the Danish magazine Fjernvarmen, Kristjansson et al. (2005-2).

In the present work the following design characteristics will be assumed:

- Space heating design load 7.7 kW and an oversizing of the radiators by a factor of two, resulting in a return temperature of 40°C when the supply temperature is 80°C.
- The year will be divided into 12 heating states, according to the model in Bøhm (1984). In each state, tapping will take place and the water heater will be idle. On an annual basis, 2300 kWh is used for domestic hot water and 17700 kWh for space heating. In addition to this, heat losses from the water heaters will be taken into account.
- The supply temperature varies from 80°C at design conditions to 60°C in the summer period. The number of operation hours in each heating state is based on Bøhm (1984) and shown in Figure 4.2.4.

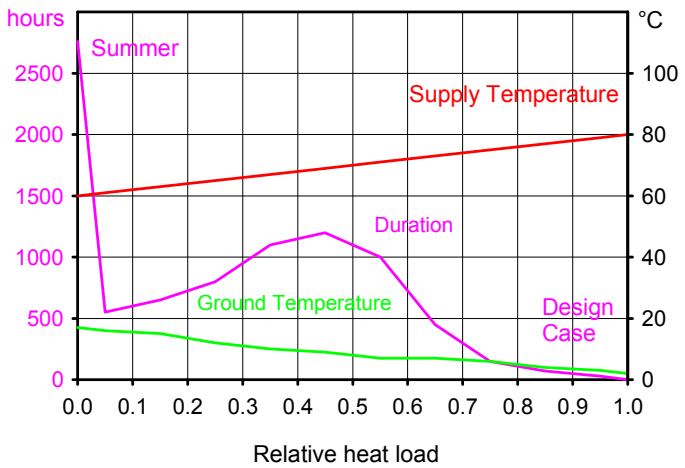

Figure 4.2.4: Time duration diagram for the Danish heating climate in Nykøbing/Falster.

Figure 4.2.5 shows the return temperature from the radiators as a function of supply temperature.

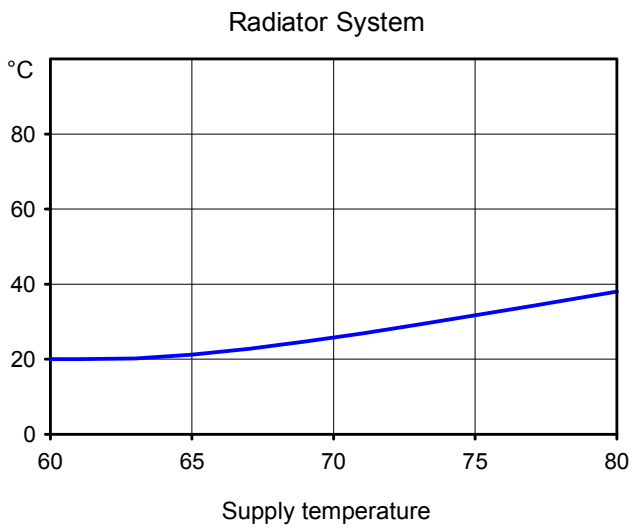

Figure 4.2.5: Return temperature from the radiator as a function of supply temperature and heating load.

The temperature model of a HWT and a HWHEX is shown in Figures 4.2.6 and 4.2.7.

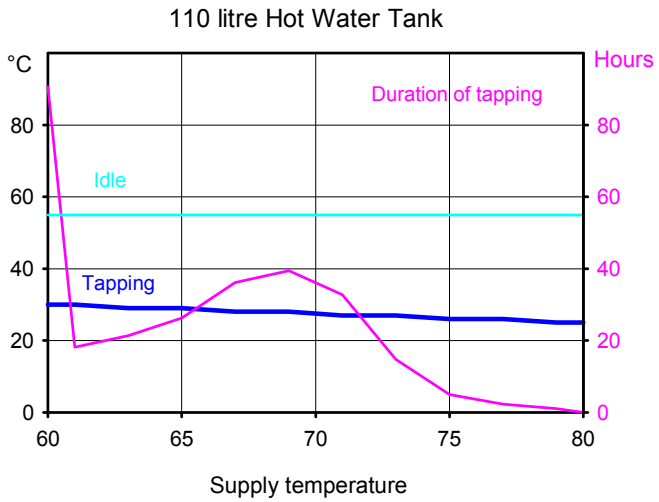

Figure 4.2.6: Temperature model for HWT

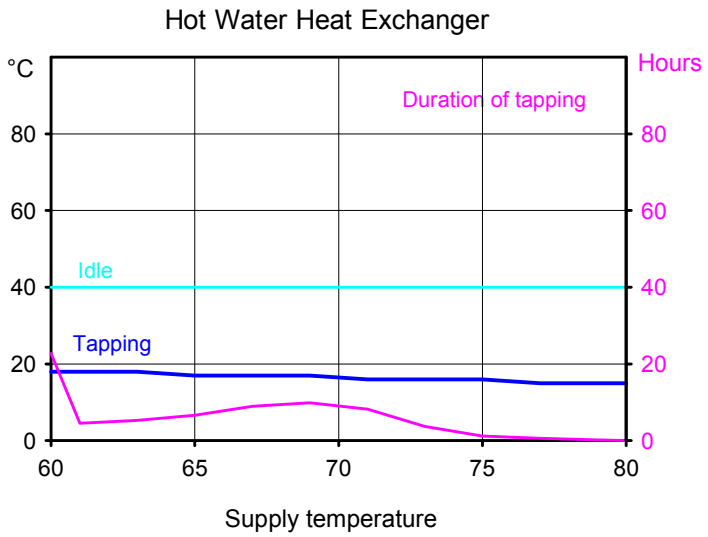

Figure 4.2.7: Temperature model for HWHEX

4.2.3 Aggregation

Space heating

The Danish tradition is to apply an aggregation factor for space heating demands which decreases by the number of houses, ending by a factor of 0.62 for several houses. As the design case is a steady state condition of outdoor temperature of -12 °C, it will be assumed in this work that all building areas should be fully heated all the time at this temperature. In other words, the aggregation factor is taken as 1.

Hot water preparation

Several models have been proposed for the aggregation of hot water loads for an ensemble of customers. In this work the model by Kristjansson, Thorsen (2006) will be used. The model is shown in Figure 4.2.8.

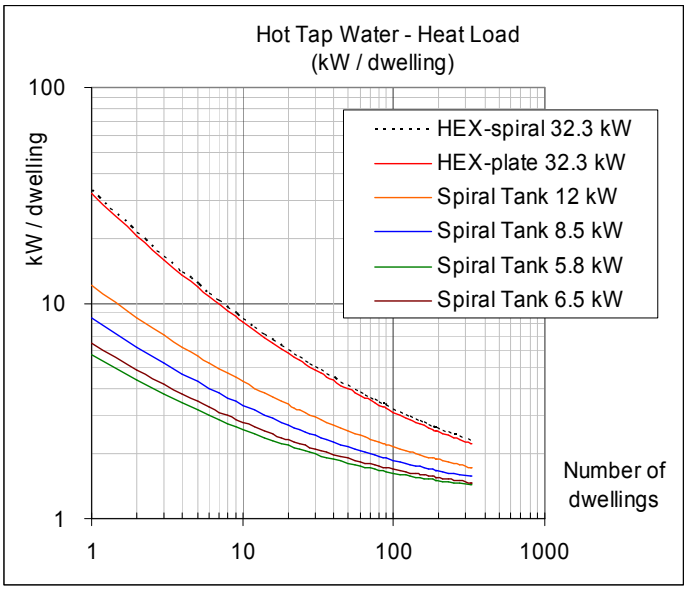

Figure 4.2.8: Heat demand for hot water loads as a function of the number of dwellings and the type of water heater.

Due to the different ability for cooling the DH water of a plate heat exchanger and a tank with built-in spiral, the different type of water heaters will affect the flow in the DH system as shown in Figure 4.2.9.

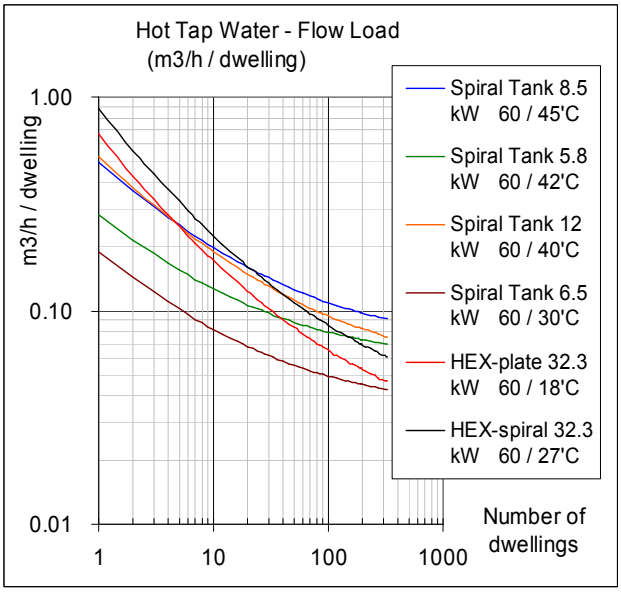

Figure 4.2.9: Flows from hot water loads as a function of the number of dwellings and the type of water heater.

Design load and summer loads for Peter Freuchenvej area

By applying the above models, the following heat loads are found for the 16 buildings:

- Space heating loads: 124 kW
- System with Hot Water Tanks: 48 kW, total 172 kW.
- System with Hot Water Heat Exchangers: 112 kW, total 236 kW.

Measurements

Data collection started in July 2006 from the 16 buildings and from the shunt in October 2006. The following periods have been selected for detailed analysis:

July 17 - August 14, 2006: Max. 25 kW in buildings.

August 21 - October 1, 2006: Max. 33 kW in buildings.

January 29 - February 4, 2007: Max. 150 kW in the area (outdoor temperature 5ºC).

June 15 - June 21, 2007: Max. 33 kW in buildings, max. 60 kW in the area.

July 16 - July 22, 2007: Max. 18 kW in buildings, max. 40 kW in the area.

Some measured heat loads will be shown in Figures 4.2.9-4.2.12.

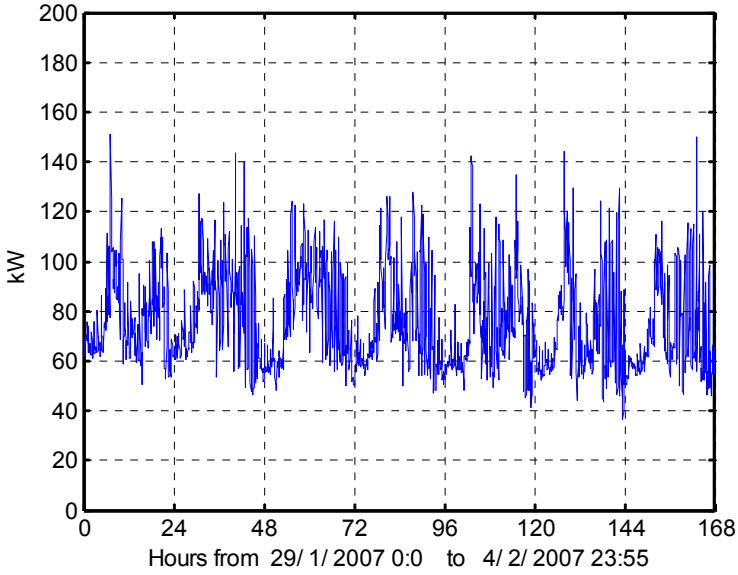

Figure 4.2.9: Winter loads at +5°C at the entry to Peter Freuchenvej area.

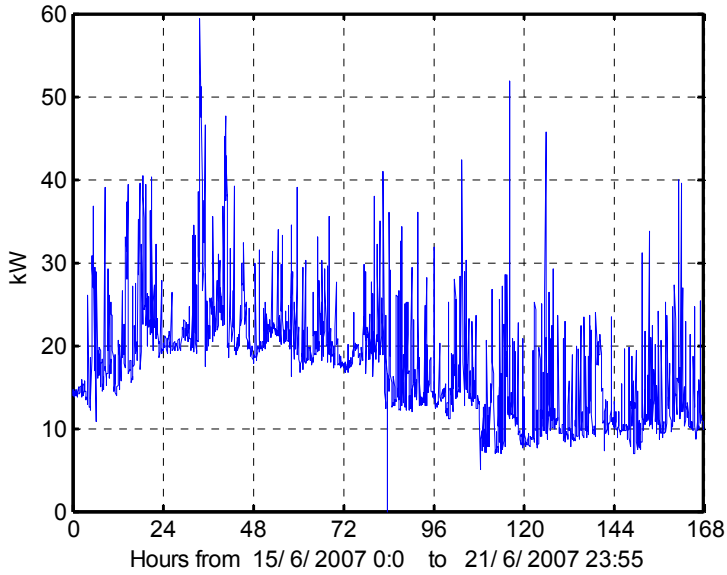

Figure 4.2.10: Summer loads at the entry to Peter Freuchenvej area.

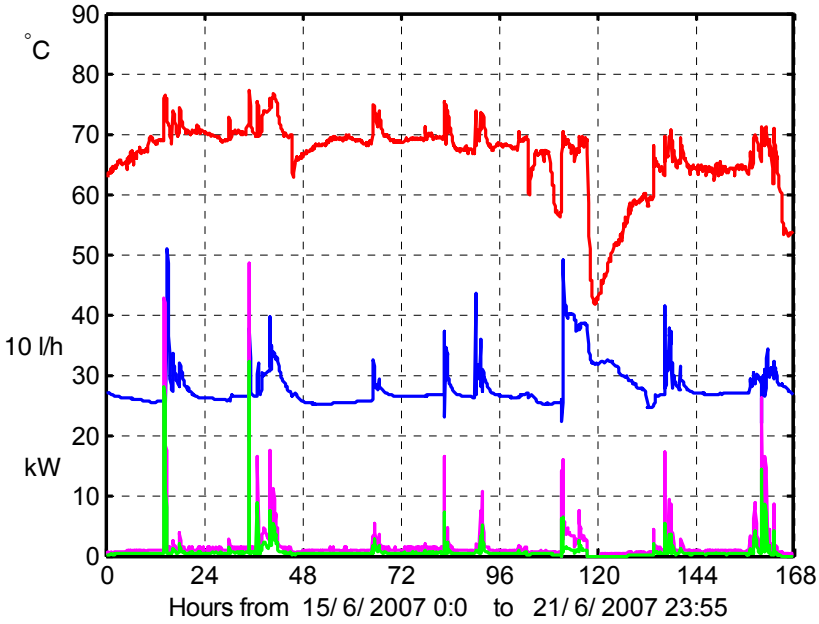

Figure 4.2.11: Building with hot water heat exchanger. Heat loads (green), flows (purple), and supply (red) and return (blue) temperatures.

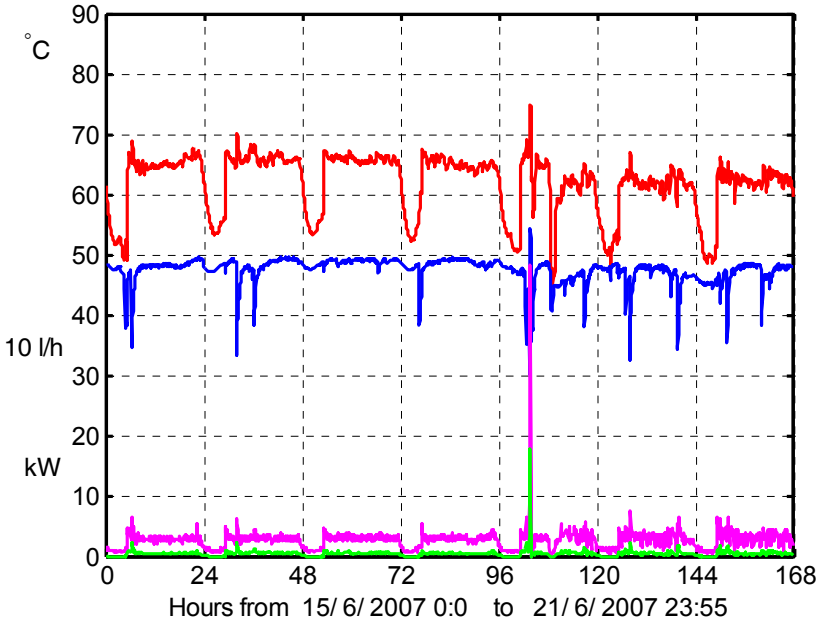

Figure 4.2.12: Building with Hot Water Tank. Heat loads (green), flows (purple), and supply (red) and return (blue) temperatures.

As can be seen by comparing the diagrams in Fig. 4.2.11 and 4.2.12, the return temperature in the systems with hot water tanks are about 10°C higher than the return temperatures from the systems with hot water heat exchangers. In these latter systems, therefore the heat losses are also higher.

5 Techniques for reduction of piping costs and heat losses from heat distribution networks

Summary

This chapter describes methods and techniques, which in the last years have been developed especially for areas with low heat demand density. A big deal of the development has been achieved in development projects in Denmark, Sweden and Finland. Compared to standard technology, these achievements concern new material for pipes and insulation, new design of pipes, the way to make routing for district heating pipes and also how to reduce heat losses by other measures, i. e. reduction of pipe diameter in combination with advanced flow control.

Definitions:

Single pipe (-pair):	Individually insulated pair of media pipes
Twin pipe:	Co-insulated pair of media pipes of the same dimension
Double pipe:	Co-insulated pair of media pipes of dissimilar dimensions
Triple pipe:	Three media pipes co-insulated, two forward pipes, one return pipe
Asymmetric insulation:	More insulation around forward media pipe than around backward media pipe – applies to all the pipe types above.

5.1 Introduction

In connection with the heat supply of low density heating areas, two things must be realised: As illustrated in Figure 5.1, the lengths of the service pipes will constitute a large proportion of the total length of the network, often 50 % or more. Secondly, the temperature and pressure loss in the service pipes can influence temperatures and pressures in the whole distribution network. Thus heat loss, temperature decline and pressure loss in the "last" service pipes should be considered carefully.

In order to design and construct an effective heat distribution network, several items must be taken into account ("best choice or "best possible" is used here in the sense of "most economic" over a certain period, f. i. 30 years).

A. The best possible lay-out (routing) of the network
B. The best possible design with regard to number of media pipes, 2, 3 or 4 pipes.
C. The best choice of materials for the media pipes, i.e. steel, copper or plastic (PEX, PB)
D. The best choice of insulation properties and diffusion barrier
E. The best choice of casing, single or co-insulated, stiff or flexible pipes
F. The optimum pipe cross section design
G. The best way of installing the pipes, excavation or "shooting"
H. The best choice of house units, i.e. a direct or an indirect connection of the space heating system, domestic hot water preparation by a Hot Water Tank or a Hot Water Heat Exchanger

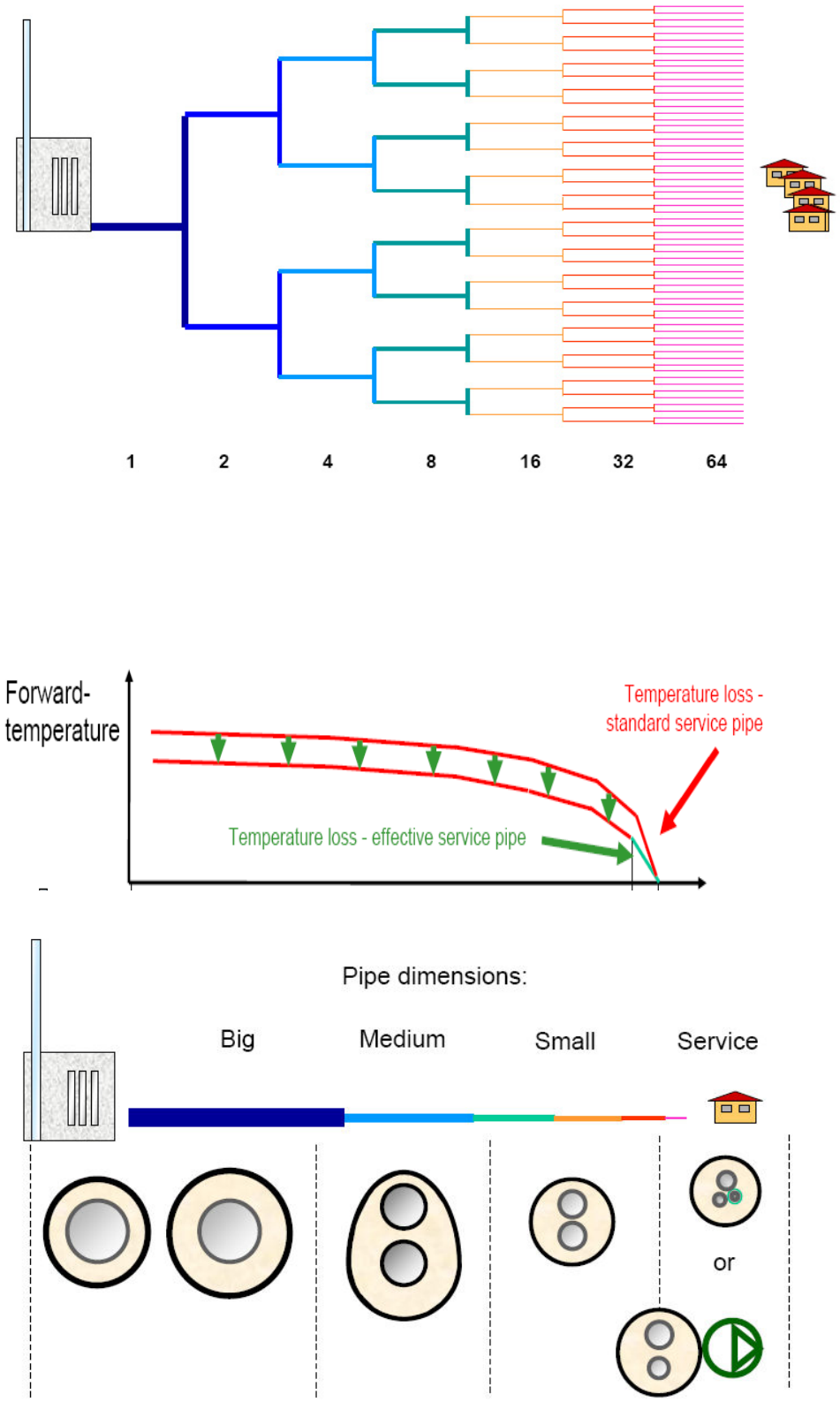

Figure 5.1: Top part shows the importance of the service pipes in number and the effect on the whole distribution network from the temperature decrease in the "last" service pipe. Bottom part shows possible pipe designs from single pipes near the plant to triple pipes and twin pipes with a booster pump at the customer.

5.2 Discussion of technical solutions for district heating in low line density areas

Ad A: lay-out (routing) of the network

In principle the network should be as short as possible, and easy to install. In some cases pipes have been installed inside the building envelope to utilise the heat loss for space heating, however, this solution is not much liked by the DH companies. In the renovation of Peter Freuchenvej, some pipes originally placed in crawl spaces beneath the floor were replaced by flexible pipes outside the building. Although this gives a slightly longer trench, see Table 8.1, it is more cost-effective and easier to repair.

In the Swedish Sparse District Heating programme (Pohl, Klingman, 2005), another solution was offered in which several buildings were supplied from a ***central substation outside the premises*** (Figure 5.2). Each building is supplied from a separate service pipe. A major advantage is claimed to be easier installation without T-joints (Gudmundsson, 2006-1).

There will, however, be a need to draw electricity, cold water and signal circuit from the house to the service box. Such a system is in use in Trelleborg, Sweden since 2007. There is a four-pipe service pipe from the substation to the house, with a "reversed hot water circulation"-mode. When the hot tap water demand from the house is high, the flow direction of the hot water circulation pipe is reversed, thus allowing the hot water to flow to the house in two pipes. This will enable installing smaller dimensions of DHW pipes, which will reduce heat losses.

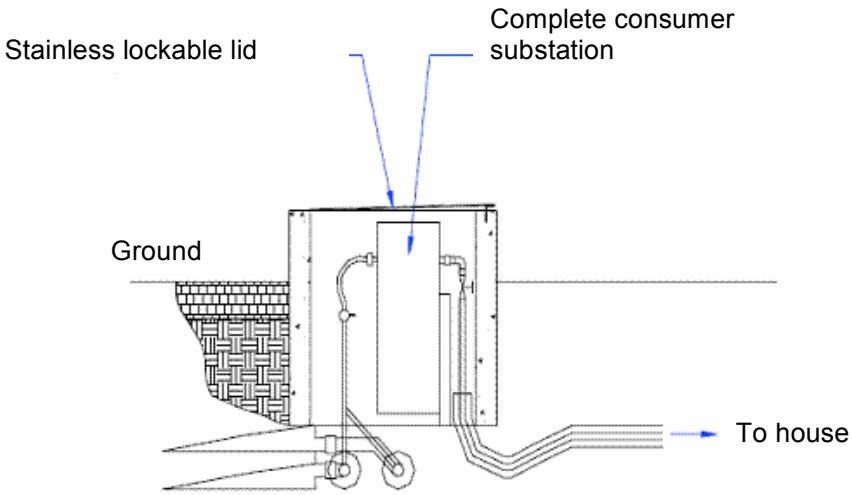

Figure 5.2: Service box for customer substation. Approx. 1m² area, 20 cm above ground level

However, so far this solution has not been generally accepted by the DH utilities.

Another solution, which is included in our analysis, is the so called ***house- to-house connection***. It is also disliked by many DH companies, but also used successfully in some areas (Cederborg, Nordgren (2005), Gudmundsson (2006-2), Gudmundsson (2006-3). In our project, cf. section 6, we have shown that house to house connection will in fact reduce installation costs and heat losses.

Ad B: The best possible design with regard to number of media pipes, 2, 3 or 4 pipes.

Some systems with 3 or 4 media pipes have in fact been built. One major advantage is the possibility to shut down the one or two pipes supplying the space heating system in the summer period. However, when all pipes are in operation, the heat loss will be bigger compared with a traditional two-pipe system.

In Denmark, recent work has been carried out with a new type of service pipe with three media pipes, i.e. one return pipe and two supply pipes (Figure 5.3, a,b). The idea is that when the heat load is moderate, the smallest of the supply pipes will be used together with the return line. When the load is high, for instance when a hot water tapping takes place, the second and larger supply

will be in operation. The operation is controlled by a flow switch (or similar) to open the control valve in the larger supply pipe.

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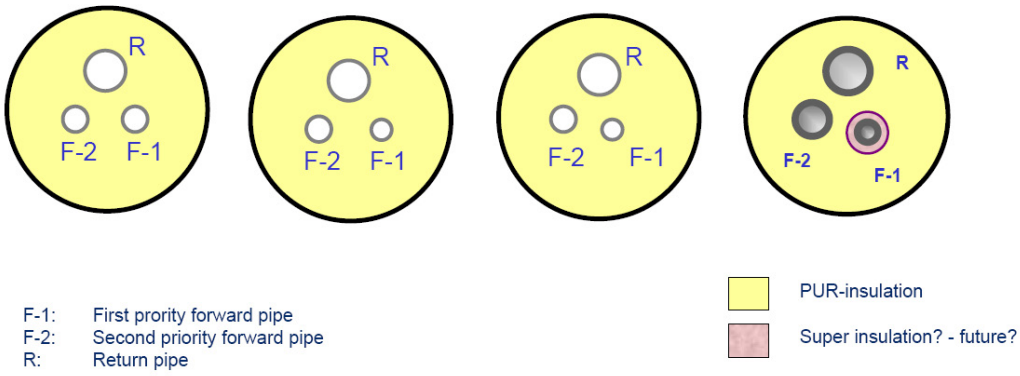


Figure 5.3a: Example of triple pipes, present and future one with vacuum insulation. The placement of the three media pipes can be optimised as indicated in the figure.

Figure 5.3b: The test pipes in Nykøbing Falster; (Bøhm, Frederiksen and Christensen, 2005).

In addition, a booster pump can be used to ensure the supply (Figure 5.4). Experiments carried out in Nykøbing Falster, (Kristjansson, Bøhm 2005-1), showed that the booster pump will be in operation for a limited period of time per day, approximately 0.5 hours.

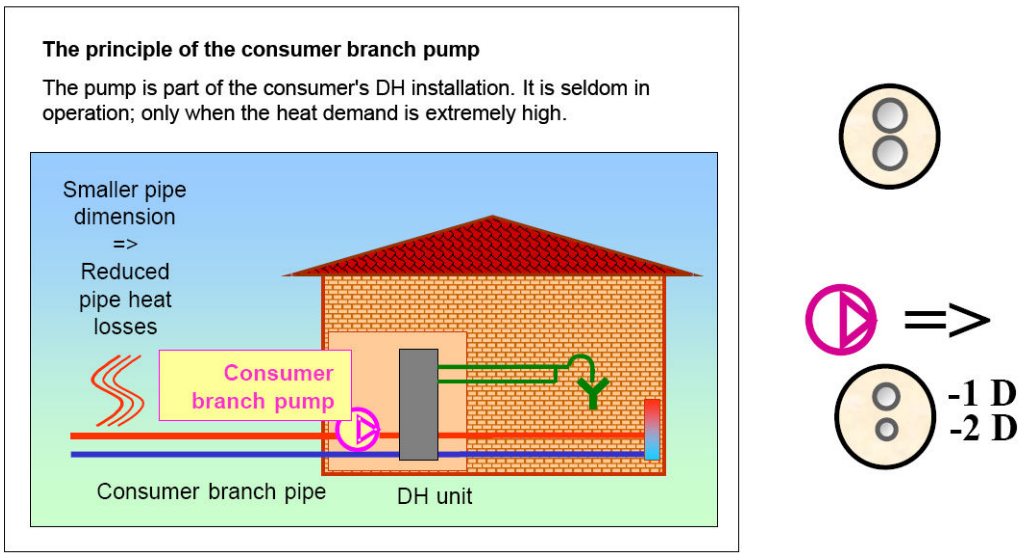


Figure 5.4: Principle of the branch (or booster) pump. It will reduce the service pipe dimensions.

Ad C and H: The best choice of materials for the media pipes (steel, copper or PEX) and the best choice of house unit.

From bad experiences when DH was young (and from topological differences), the DH systems in Denmark, Sweden and Finland have developed differently. The Danish systems are low-pressure, low-temperature systems with many direct connections of detached houses. Moreover, hot water tanks are very common, although hot water heat exchangers are also in use. Many service pipes are made of PEX, assembled by compression fittings, while copper service pipes are used to a much less extent in Denmark. As part of the Swedish Sparse District Heating Programme, Sandberg (2004) carried out a survey of Danish practice with regard to connection of detached houses.

Ad D: The best choice of insulation and diffusion barrier

It is sometimes claimed that the preinsulated pipe was developed in the late 1960'ties, but in fact, a continuous improvement of the pipe and the fittings has been going on since then.

Today, heat conductivities of below 0.023 W/(mK) have been documented in accredited laboratories. Micropore foam based on cyclo-pentane and continuous production without spacers are common technology today. The ageing of the foam, i.e. the replacement of cyclo-pentane by air, can today be effectively hindered by a diffusion barrier, which is standard on some pipe dimensions. Although the long-term effect has not been documented yet, it is expected that the heat conductivity of the polyurethane (PUR) foam will stay low for the lifetime of the pipe.

Some attempts to replace the PUR foam with foams made of other plastics are going on at an experimental basis, however, PUR foam is dominant on the market today. Vacuum insulation is available for some applications, for instance refrigeration, but is still not economically attractive for DH pipes.

Ad E: The best choice of pipe design (single or co-insulated pipes)

The use of co-insulated pipes (twin pipes, pair of single pipes) where the two media pipes are placed in a common casing was used in Sweden and Finland long before it got popular in Denmark 10 years ago. Today, twin pipes are used almost exclusively for the smaller pipe dimensions in many countries.

In the following we will quantify savings by using an advanced pipe design compared with a traditional design. To this end, we will consider a distribution pipe and a service pipe.

80 mm (nominal) distribution pipe

We will choose a 80 mm pipe as a typical distribution pipe. This pipe has a capacity of 800 kW (at 100 Pa/m and 40 K temperature difference), capable of supplying approximately 80 detached houses with heat. We will evaluate the heat losses at supply and return temperatures of 80˚C and 40˚C, respectively, and a ground temperature of 8˚C. For twin pipes we will assume that the media pipes are placed vertically with the return pipe located closest to the ground surface. This gives the lowest heat loss compared with having the supply pipe on top and compared with horizontally placed media pipes.

How can we make a fair comparison of heat losses from different pipe systems and how can we take different investment costs into account? In a comparison of single pipes and twin pipes (circular and ellipsoidal), Jonson (2001) assumed that the same amount (volume) of insulation must be used in both pipe systems. However, here we will assume that ellipsoidal and egg-shaped profiles must be made from circular casing pipes available on the market.

The thermal conductivity is assumed to be 0.0265 W/(m·K), representing present technology of new polyurethane foam for straight pipes. The following pipe systems are considered:

A. Pair of single preinsulated pipes ø80/160 with D_p = 88.9 mm, D_i = 157.8 mm.

B. Circular twin pipe ø80/80/250 with D_p = 88.9 mm, D_i = 248.3 mm. Distance between media pipes 25.1 mm.

C. Egg-shaped twin pipe 80/80/250 (Not commercially available).

The heat loss coefficients and the heat losses are shown in Table 5.1, obtained from analytical expressions in case A, the multipole method in case B, and the finite element method in case C, cf. Appendix 1.

Table 5.1: 80 mm (nominal) distribution pipe. Heat loss coefficients, heat losses, resources (cross-section area) and costs.

DISTRIBUTION PIPE	HEAT LOSSES					RESOURCES			COSTS
	U_{11} supply W/(m·K)	U_{22} return W/(m·K)	U_{12} W/(m·K)	q_{tot} W/m	Relative loss %	Casing cm^2	Insulation cm^2	Gravel m^2	Investment index %
A Single pair	0.2664	0.2664	0.0113	26.53	100	31	270	0.480	100
B Circular twin	0.2517	0.2534	0.0784	18.08	68	31	360	0.370	90
C Egg-shaped twin	0.2264	0.2735	0.0799	16.74	63	31	310	0.320	88

Please observe that for circular twin pipes, the U_{11} and U_{22}-values for the supply and return pipes are very similar, although U_{11} is smaller than U_{22}. For twin and egg-shaped pipes, the U_{12}-value is high compared with the U_{11} and U_{22}-values, i.e. the heat exchange between the two media pipes is significant for these pipe systems in comparison with a pair of single pipes.

It appears from Table 5.1 that an egg-shaped twin pipe can reduce the heat loss by 37 % compared with a pair of single pipes. Table 5.1 also shows a comparison of the resources needed for the three different pipe systems with regard to casing, insulation material, and the amount of gravel in the excavation (ground coverage 0.5 m, side and base coverage 0.1 m, spacing between single pipes 0.15 m). Even if the amount of insulation is bigger in the case of co-insulated pipes, the savings in component works and for gravel needed result in a cost reduction of 10 % by installing circular twin pipes. Additional savings of a few percent can be achieved by using egg-shaped twin pipes.

Service pipes

In this case we will consider both traditional single service pipes of cross linked polyethylene (PEX), two types of twin pipes and a new pipe design, the triple pipe with two supply lines and one return line, see Figure 5.3. The basic idea of the triple pipe is that heat is supplied by the smallest supply pipe in the normal case. When big heat demands occur, for instance when tapping of domestic hot water takes place, extra heat is supplied through the second supply line. The triple pipe not only has a smaller heat loss than traditional service pipes, but it also provides a better hot water comfort. The triple pipe can be combined with a booster pump in the house, which can result in a reduction of media pipe dimensions compared with the dimensions considered below.

Investigated service pipes:

A1. Pair of single pipes ø20/66 (exterior diameters in mm)

A2. Pair of single pipes ø25/77

B1. Twin pipe ø20/20/90

B2. Twin pipe ø25/25/110

C. Triple pipe ø15/18/20/105 (Not commercially available).

Table 5.2: Heat losses, resources (cross-section area) and costs of service pipes.

SERVICE PIPES	HEAT LOSSES W/m				RESOURCES			COSTS
	No tapping 60/50 °C	Tapping 60/20 °C	Weighted with time	Relative loss %	Casing cm^2	Insulation cm^2	Gravel m^2	Investment index %
A Pair of single pipes ø20/66 ø25/77	11.51 12.14	7.30 7.70	11.03 11.95	92 100	8.3 9.7	54 74	0.297 0.316	96 100
B Circular twin ø20/20/90 ø25/25/110	8.80 8.80	5.80 5.58	8.67 8.67	73 73	5.6 7.5	52 78	0.186 0.205	73 79
C Triple pipe ø15/18/20/105	6.61	6.65	6.61	55	6.5	71	0.200	79

For the twin pipes and the triple pipe we will assume that the return pipe is located closest to the ground surface. The thermal conductivity is assumed to be 0.028 W/(m·K), based on polyurethane foam used for flexible service pipes. We will evaluate the heat losses at a summer situation with a (local) supply temperature of 60˚C and a ground temperature of 14˚C. When tapping of domestic hot water takes place, a return temperature of 20˚C will be assumed. When tapping does not take place, the return temperature is set at 50˚C. In this case, there is no flow in the second supply line of the triple pipe and its temperature is set at 32.3˚C ensuring zero heat flux.

The heat losses for different temperature sets are shown in Table 5.2. Measurements on a triple service pipe in Denmark, (Bøhm, Frederiksen and Christensen, 2005), show that the second supply pipe is only in operation for about 1 hour per day. Therefore, Table 5.2 also includes a time-averaged value for the heat loss. In the case of tapping of domestic hot water, the triple pipe has a higher heat loss than the twin pipe, but this situation is reversed when no tapping takes place.

Many district heating companies in Denmark use the ø25/77 pipe as the normal service pipe and we will take it as the reference case in the comparisons. Compared with this pipe, the triple pipe has a heat loss of only 55 %. However, it can be argued that the ø20/66 pipe is a more fair comparison with the twin and triple service pipes as it has the same capacity as these. On the average the triple pipe reduces the heat loss by 24 % compared with the twin pipes and by 40 % compared with the pair of ø20/66 pipes.

In Table 5.2, comparison is also shown of the resources needed for the different service pipe systems with regard to casing and insulation material and the amount of gravel in the excavation. Circular twin pipes result in a reduction in the investment index of 21-27 % compared with the reference case. For the triple pipe the reduction is 21 %.

Ad F: The optimum pipe cross section design

Heat losses and resource requirements of traditional and of co-insulated pipes

Recent information about savings obtained from twin pipes compared to single pipe pairs may appear to be somewhat confusing. Insulation classes of these two basic pipe types are not comparable because of different insulation cross-section geometrics. A comparison between heat losses from different basic pipe types should take into account all costs and benefits of both pipe systems. In this case, the benefits are the heat loss savings while the costs are the resources used for production and installation. The evaluation here is based on a model embracing multivariable regressions of material and labour requirements as well as price and investment statistics, Kristjansson et al. (2004). The model takes into account different joining and component costs of single and twin pipe systems together with network geometrics.

Savings of twin pipes (with equal media pipe dimensions)

In Figure 5.5, two series of PEX20-single pipes are compared to three series of PEX20-twin pipes. Each of the five series includes a range of casing diameters which makes up each of the five

curves in the figure. All pipes have the same flow capacity and temperatures of 70/30/8˚C (forward/ return/ soil). The curves show that an increase in casing size decreases the heat losses, but the reduction fades out with increasing casing sizes while the rate of resource requirements increases with growing rates. This sets an effective limit to the feasible extra insulation in case of each series.

The first of the two single pipe series in the upper part of the figure includes standard insulation on both media pipes while the second series includes extra insulation of the forward pipe, saving more than 10 % of the heat losses, and moving the curve downwards. But simultaneously, the curve is moved to the right because of the increased resource requirements, limiting the net savings to an insignificant level as can be seen from the fact that the two curves are almost on top of each other.

The short curve in the figure shows the commercial PEX20 twin pipe with the casings of 90 and 110 mm, respectively, which both have the same media pipe gap of 19 mm - media pipe gaps have been kept in standard figures as far as possible for practical reasons. A more general version of the twin pipe with the total range of casing diameters is represented by the next curve below. Here, the gap is adjusted in accordance with the fact that the relative ratio of heat loss to heat fluxes strongly depends on the relative placement of the media pipes inside the insulation. In this series, the *relative* cross section geometry is kept the same for different casing diameters, with a relative thickness of the three insulation layers of 35+30+35 % (return side gap + media pipe gap + forward side gap).

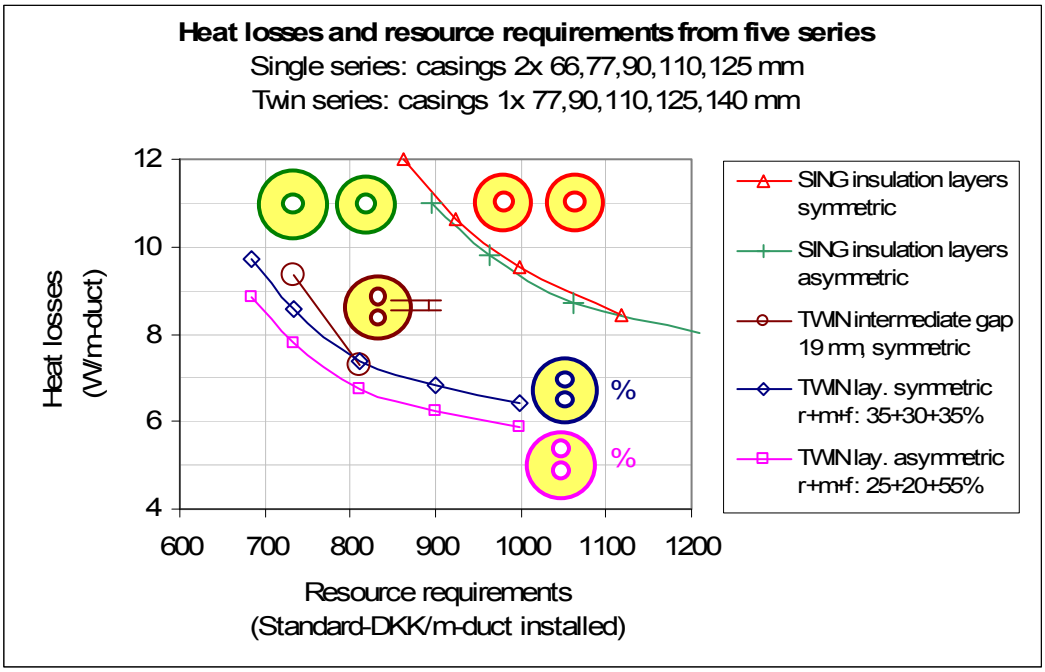


Figure 5.5: Heat loss from five series: 1:The traditional symmetrically insulated single pipe series with casings of 2 x 66, 77, 90, 110, 125 mm, 2: Asymmetrically insulated single pipe series with forward casing one dimension up, 3: Two twin pipes with casings of 1 x 90, 110 mm and symmetric insulation with 19 mm intermediate gap between media pipes, 4: Twin pipe series with casings of 1 x 77, 90, 110, 125, 140 mm of symmetric insulation with intermediate gap of 30 % of all three insulation layer thicknesses (pipe gaps) together. 5: Same twin pipe series but with asymmetric insulation with layer thicknesses in the ratios 25+20+55 % (return side gap + intermediate gap + forward side gap).

A *vertical* comparison between this twin pipe curve and the single pipe curve leads to the conclusion that the twin pipe *in principle* and in rough numbers saves 40 % of the heat losses (PEX 20 mm). However, savings obtained by increased casing diameters seem to fade out more sharply in case of twin pipes than in case of single pipes (depends on cross section design). Commercial conditions may limit the size of casings, which may reduce heat loss savings to a smaller figure than indicated above, but then this saving reduction is converted into investment savings.

The last and nethermost curve represents a twin pipe with asymmetric insulation with a thicker insulation layer around the hot forward pipe, obtained by replacing the media pipes inside the casing so the relative thickness of the three insulation layers is 25+20+55 % (return side gap, intermediate gap, forward side gap). From the figure, it appears that further savings of about 10 % can be obtained, and this almost corresponds to a whole insulation class (casing diameter). These savings are relatively independent of the casing diameter.

Another argument for using asymmetric insulation of twin pipes is that less than half of the savings of twin pipes are obtained from the forward pipe. While most of the losses from the return pipe are saved (maybe 80 %), savings of the forward pipe losses are more limited (maybe 30 %) even though the total savings are 40 %. In case of service pipes, the temperature loss is considerable, often 2-3ºC. This supports asymmetric insulation of twin pipes.

Savings of double pipes (with different media pipe dimensions)

Another method for reducing the heat losses from the forward pipe is to reduce the dimension of the forward pipe so the innermost and most important insulation layer becomes thicker around the forward media pipe. The production and laying costs stay at the same level, but now the water transport capacity of the pipe pair is reduced. A general comparison for most dimensions can be found in Kristjansson et al. (2004), but here we will focus on service pipes. The study starts with a PEX 20 mm and gradually reduces the dimensions of the media pipes to see the effects. The resulting plots of heat losses and the hydraulic capacity are shown in Figure 5.6. The figure includes three groups of double pipes; the first group with media pipes of the same dimension (twin pipes); the next group with a double pipe with forward media pipe one dimension less than the return pipe, i.e. (forward/return) 18/20, 16/18 mm, etc.; while in the last group, the forward pipe has a dimension two dimensions less than the return pipe (16/20, 14/16).

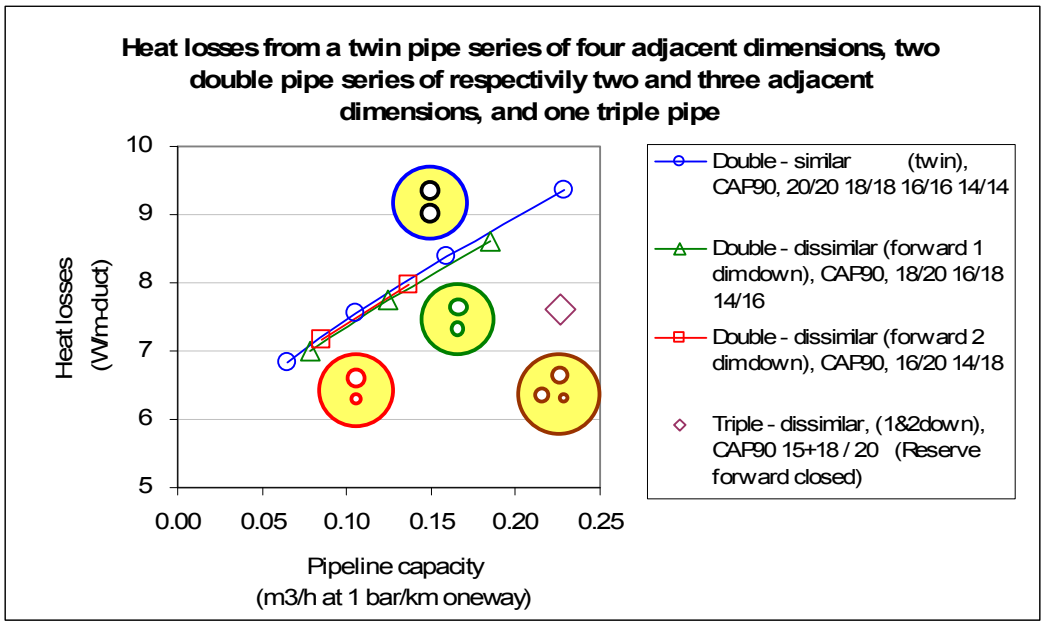


Figure 5.6: Heat losses from various designs of pipes where the designs affect the transport capacity of the pipes. All the pipes have the same casings, which in this case involves about the same resource requirements. The pipes compared are the twin pipe (similar pipe dimensions), double pipe (dissimilar pipe dimensions), with forward 1 dimension smaller, double pipe with forward 2 dimensions smaller, and finally the triple pipe with three different and adjacent dimensions.

From the comparison between the three plots, it appears that *the principle* of using different media pipe dimensions does not lead to any noticeable savings, only a few percent (in the case of small pipe dimensions).

On the contrary, Figure 5.6 shows that if double pipes are used together with twin pipes, the consequently better possibility of flow capacity adjustment may save up to 8 or 10 % in individual cases, or maybe 4 % in average for a large number of service pipes, and this opportunity of "cheap" savings should not be left out.

Another argument for using a small forward media pipe dimension is that in case of small dimensions, especially as regards service pipes, the heat loss savings in the forward pipe also lead to temperature loss savings. This means higher comfort or less flow, and in critical areas of the network, these temperature savings should lead to lower supply temperature from the heat plant, which again reduces the heat loss in the whole network, cf. Figure 5.1.

Temperature losses may also be critical in circumstances with uneven consumption (for example pure hot tap water usage). Less heat is lost when the pipe cools down during a night period without consumption, and small forward pipe dimensions cause the hot district heating water to reach the customer faster (e.g. in the morning through the previously cooled down service pipe). It is though a canard that a small pipe dimension saves temperature owing to higher water velocity under static conditions. The reason is that a small pipe dimension also holds less water to cool, and these two geometric factors are of the same origin and counterbalance each other. Consequently, static temperature savings caused by reduced pipe dimensions are only possible because of heat loss savings.

All these conditions lead to the important conclusion that even if double pipes at first sight do not have advantages compared to twin pipes (in case of small pipe dimensions), the many side effects bring along considerable improvements. The asymmetrically insulated double pipe (which means dissimilar pipe dimensions) must be considered a better option than the symmetrically insulated twin pipe.

However, there is still one additional pipe type with considerable potential savings, i.e. the triple pipe. One design of this pipe has been plotted as a single point in Figure 5.5. The triple pipe combines the advantage of sufficient capacity of a large pipe dimension and reduced heat loss from a small forward pipe dimension. Both can be obtained by a design with two forward pipes instead of one. The two forward pipes are of dissimilar dimensions, which are both smaller than the return pipe. Only the small forward pipe is in operation most of the time, but the large forward pipe is opened in case of short peak loads. The large forward pipe can also serve as a pure design reserve, i.e. it is not in operation, and this principle leads to designs with small pipe dimensions, saving heat losses. It appears from the figure that the triple pipe is superior to other pipe designs. However, the data point on the figure indicates the heat loss when only the small forward pipe is in operation, and this is not correct 2-4 % of the time. Therefore, the average heat losses will increase somewhat. Furthermore, dynamic operation conditions must be taken into account. Relatively simple test site measurements of a triple pipe in operation have indicated that a fair level of savings can be obtained. It should be noted that the triple pipe cannot be applied to all customer unit types, and this kind of pipe also has requirements as to the principal design of the customer substation and the flow control.

5.3 The heat exchange between the two media pipes and the influence on the return temperature

It is sometimes argued that the return line in a twin pipe will be heated up by the supply line to an extent that is undesired. This question can easily be addressed by use of the heat loss coefficients.

In the case of the return pipe, the heat loss can be calculated according to:

$$q_r = (U_{1r} - U_2)(T_r - T_g) - U_2 (T_f - T_r)$$

where U_{1r} and U_2 are heat loss coefficients, and T_f, T_r and T_g are the temperatures of the forward pipe, return pipe and undisturbed ground, respectively, cf. Appendix 1.

U_{1r} expresses the heat flux from the return pipe in case of no forward pipe, and U_2 expresses the heat flux from the forward pipe to the return pipe. U_2 depends on the distance between the two media pipes as well as the thermal conductivity of the insulation material.

As a rough estimate for the magnitude of the two heat loss coefficients, the following figures can be given (in case of small pipe sizes):

For copper twin pipes: $U_2 / U_1 \approx$ 45-50 %,

For cellular concrete ducts: $U_2 / U_1 \approx$ 35-50 %, depending on moisture content.

For PEX twin pipes: $U_2 / U_1 \approx 25\%$

For singular insulated pipes: $U_2 / U_1 \approx 3$ %.

This means that the heat flux from the forward pipe to the return pipe may be expected to be relatively larger in case of twin pipes than in case of single pipes, and also larger in case of copper twin pipes than in case of PEX-twin pipes (by tradition, a shorter distance between the copper media pipes is applied).

In order to illustrate the amount of heat flux from the forward pipe to return pipe, let us consider the 80/80/250 egg-shaped pipe and the twin pipe PEX 20/20/90 (f/r/casing mm). The heat exchange in the distribution pipe is shown in Figure 5.7 in case of a constant supply temperature of 80˚C and return temperatures varying between 20 and 80˚C. It appears that only for return temperatures below 30˚C will the heat loss from the return pipe be negative. It also appears that at 80˚C, the heat loss from the return pipe will be bigger than from the supply pipe, as the return pipe is located closest to the ground surface.

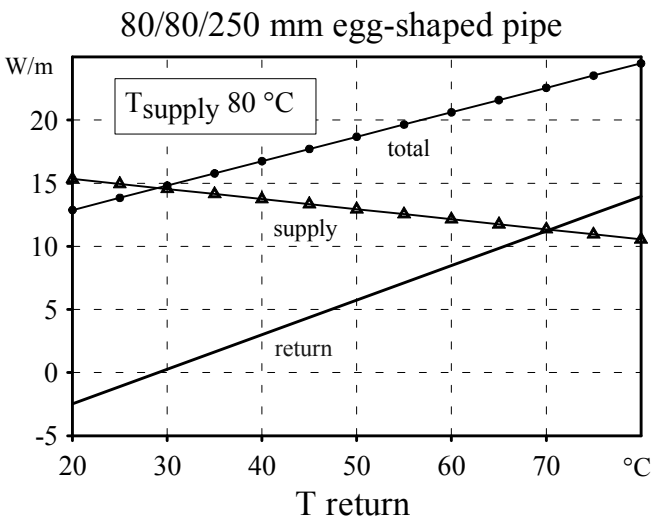


Figure 5.7: Total heat loss from 80 mm (nominal) egg-shaped twin pipe as well as the heat loss from the supply and return pipe, respectively. The return temperature varies between 20 and 80 ºC, while the supply temperature is kept at 80 ºC.

In Denmark, the small twin pipes are often separated by a distance of 19 mm. Figure 5.8 shows variations in heat fluxes caused by variations in the return temperature when the forward temperature is kept constant. The net return pipe heat loss is equal to the heat loss from the return pipe to the surroundings minus the heat contribution from the forward pipe. The figure shows that if the return temperature stays above 23ºC, then the heat contribution from the forward pipe is smaller than the return pipe heat losses to the surroundings, and therefore the return temperature will not increase.

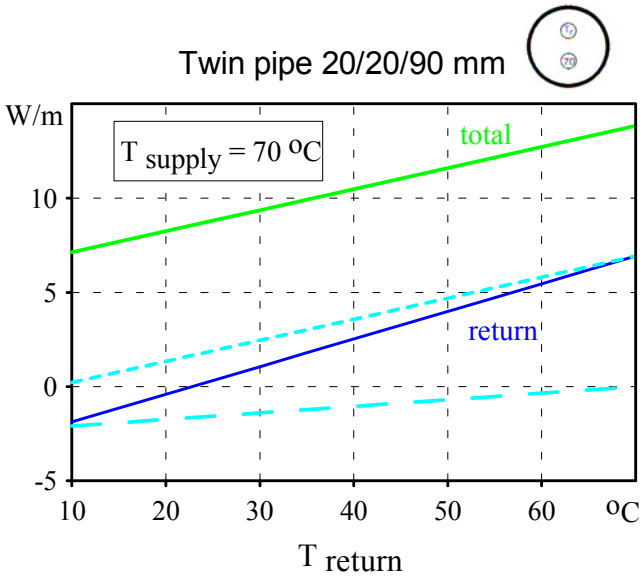


Figure 5.8: Heat losses at different return temperatures while the forward temperature is kept at 70ºC. The total heat losses from both pipes are shown in green while the return pipe net heat loss (blue line) is the difference between the gross heat loss from the return pipe to the surroundings (upper dashed line) and the contribution of heat flux from the forward pipe (lower dashed line). Twin pipe 20/20/90 mm f/r/casing, PUR insulation λ=0.028W/(mK).

In general, the return temperatures in district heating systems stay within the range of 30-50ºC, depending on load, customer mix, etc. However, as to service pipes, the return temperature variations may be larger. The measurements documented in Bøhm, Frederiksen and Christensen (2005) showed that the return temperature went down to 25-30°C for short periods of time, caused by hot tap water consumption.

Figure 5.9 shows the heat losses from the service pipe when the distance between the two media pipes is increased from 0 to 46 mm. In the latter case, the media pipes are touching the casing pipe from the inside.

The total heat loss as well as the heat loss from the return pipe increases with an increasing media pipe distance. If the distance is more than 10 mm, the heat loss from the return pipe is positive, which implies that the return line is not heated up. The total heat loss is minimized by minimizing the distance between the media pipes, but this situation is usually not feasible because of the large

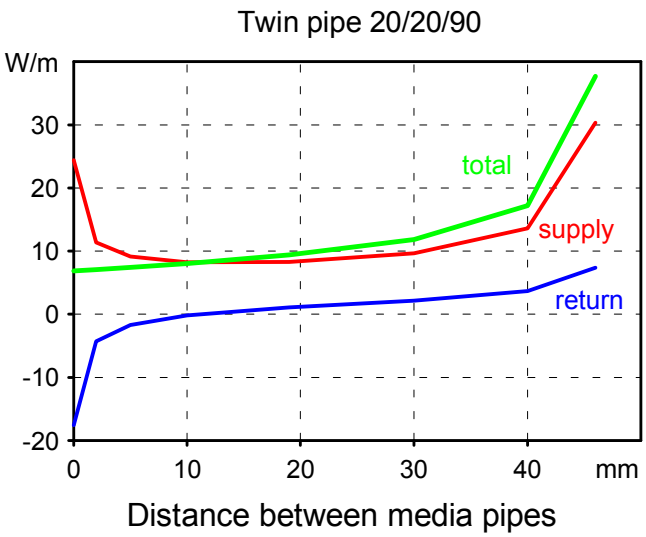


Figure 5.9: The distance between the media pipes influences the total heat losses (green), the forward pipe losses (red), and the return pipe losses (blue). Twin pipe 20/20/90 mm f/r/casing, temperatures of 70/30/8°C f/r/soil, PUR insulation λ=0.028W/(m·K).

heat flux from the forward pipe to the return pipe, which causes an unnecessary temperature fall in the forward pipe and temperature rise in the return pipe.

The calculations were made for a thermal conductivity of 0.028 W/(m·K). PUR foam of considerably better quality is available on the market today, reducing all heat fluxes including heat exchange between the two media pipes.

It can therefore be concluded that the water in the return pipe of PEX twin pipes is *not* heated by the forward pipe in general.

Ad G: Installation

The standard in Denmark and other countries for systems of small dimensions is today the use of flexible service pipes, available in rolls of 50-100 meters. Casings can be corrugated or smooth. Installation is often carried out in a combination of digging and "shooting" the service pipes.

In a Swedish R&D programme, tests have also been carried out with a new type of pipe design based on a casing made of polystyrene, called ESPEX. Cf. section 6 for description of this system. The media pipe itself is not insulated. I is shown that these pipe system can also save total system costs compared to both standard single pipe and twin pipe systems.

Ad H: The best design of the service pipe and the network with regard to pipe diameters, pressures, temperatures and heat losses.

The optimum design of the DH system is of course very important. It is difficult to give general recommendations for the design; however, the network should be designed in such a way that the available pressure difference for the supply area is fully utilised. In this respect future extensions of the DH system must be taken into consideration. In some cases, the use of a booster pump for peak load operation should be considered as this could result in smaller dimensions (cf. section 6).

The use of *friction reducing additives* will give smaller pipe diameters or lower pumping costs, but a break through of this technology has still to come (Welfels, P., 2004).

6 Cost model for heat distribution systems in district heating with low line heat density

Summary

This chapter describes a simple cost model for local district heating systems to be used for applications with low heat density. The model itself is based on spreadsheets made in Excel, which are constructed so that they show system costs for alternative constructive layouts applied on the same system. Each system is specified by house loads and geographic information of customers. The cost model addresses total costs, i.e. it includes costs for investment, for heat losses as well as pumping and costs for maintenance. In this chapter, the cost model is applied on the two system intensively analysed in this report, Neidonkallio and Nykøbing, respectively.

6.1 Objective

There are several suggestions on how to reduce costs for distribution systems in areas with low heat density. Since the major expenses, especially for low-density district heating, are costs for installation and/or heat losses, most solutions focus on lowering these costs. To lower installation costs, less expensive materials or more cost effective systems can be used, sometimes at the expense of increasing the heat losses. With better pipe insulation, heat losses are reduced, but this can significantly increase installation costs. This cost analysis seeks to evaluate the total costs for a series of system solutions, where all the installation costs and the operation costs for a period of 20 years are included.

6.2 System comparison model

A system comparison model has been developed in Excel. Costs and specific heat losses for various dimensions and insulation classes of single and twin pipes has been loaded to the model, as well as data for triple pipes and EPS pipe. All analysed systems have the same method for calculating heat loss, production costs, required pump work and annuity.

Each network system solution has its own worksheet in the Excel workbook. The lengths and dimensions for all piping in the system are specified in a separate worksheet and linked to the system solution worksheets. It is specified for each network system which type of pipes to use and which components to include in the calculations. Given the pipe types, dimensions and lengths, the total piping installation costs, heat losses and pump work are calculated (see Table 6.1). Other network costs, such as installation and material cost for a customer substation, hot water storage, meters, valves and booster pump (when applicable), are also included in the model.

6.2.1 Heat loss

Energy lost from a pipe system has a relatively high impact on the cost. The specific heat losses are calculated for different distribution areas, as they vary depending on system temperatures (T_{Supply}, T_{return} and T_{ground}). For calculating the heat loss coefficients, the following assumptions were made:

Heat conductivity:	0.028 W/(mK) [Rigid PUR]
	0.023 W/(mK) [Soft PUR]
	1.6 W/(mK) [Ground]
Soil coverage:	0.5 m (Except for low depth piping).

The pipe jackets were assumed to contain a diffusion barrier, which keeps the insulation properties of the pipes constant throughout their lifetime.

The calculations for steel pipes are done in EkoDim[1], for PEX pipes the Logstor Statech program has been used and for the triple pipe, heat loss calculations from Bøhm and Kristjansson (2005), were used.

1 EkoDim is a program for dimensioning economically and ecologically, provided by Svensk Fjärrvärme (Swedish board of district heating, www.svenskfjarrvarme.se).

Table 6.1: Example from cost calculations of the traditional system with twin pipes in Neidonkallio.

Calculation example, Traditional connection
Twin pipes, series 2 insulation (Neidonkallio)

DH network system data	
Supply temperature, T_s (°C)	87
Return temperature, T_r (°C)	43
Ground temperature, T_g (°C)	5
DT= $(T_s+T_r)/2-T_g$ (°C)	60

Heat cost (€/MWh)	32
Electricity cost (€/MWh)	68
Interest	6%
Annuity	8.72%
Depreciation time (years)	20
Number of houses	30

Piping	Lenght L (m)	Pipe cost (€/m)	Cost €	Specific heat loss q (W/mK)	Heat loss* W
Dn 25	689.0	84	57 978	0.221	9124
Dn 40	15.3	112	1 711	0.292	267
Dn 50	532.2	136	72 153	0.279	8912
Dn 65	534.7	178	94 998	0.338	10838
Dn 80	211.9	188	39 852	0.393	4996
Dn 100	184.7	230	42 472	0.393	4360
Dn 125	333.9	295	98 342	0.357	7148
Total net	2501.7	163	407 507	0.304	45645
				Heat loss (MWh/yr)	399.85

*Heat loss is calculated as L*q*DT

	Per house		System (30 houses)
Auxiliary heat losses	Per HEX (W)	Annual (kWh)	Annual (MWh)
Consumer substations	50	174	5.23

3486 hours/year are the houses assumed to fully benefit from heat losses from substation

Total heat loss (MWh/yr)	405.08

INSTALLATION	
Piping	
Distribution pipe, twin	€ 349 529
Service pipe	€ 57 978
Total	€ 407 507

ANNUAL COST	
Piping	
Heat loss	€ 12 898
Pumpwork**	€ 88
Total	€ 12 986

Consumer substation	
Piping/installation work	€ 1 430
Electric work (meter, counter)	€ 154
Remote counter	€ 110
Meters	€ 165
Total/house	€ 2 959
System total	€ 88 770

Consumer substation	
Electricity	€ 3
Maintenance	€ 5
Heat loss	€ 6
Total	€ 14
System total	€ 409

Total installation cost	€ 496 277

Total running costs	€ 13 395

Annual cost for investment	€ 43 268

Total annual cost	€ 56 663

**Pumpwork is calculated based on an assumed flow profile for each pipe dimension. Flow is calculated from a heat demand profile based on outdoor temperature.

Heat losses from heat exchangers and hot water tanks are regarded as losses only when there is no heating demand in the house, i.e. during the summer time. The remaining time, it is assumed that the building benefits from the heat lost from equipment. Note that these heat losses are relatively small when compared to the pipe heat losses.

6.2.2 Costs

The cost analysis takes into account the total investment cost (material and labour) for installing DH distribution pipes and customer substations. The economic framework for the calculations is presented in Table 6.2. The annuity is calculated for a period of 20 years. The analysis also includes cost for operation and heat losses for the same period. Annual interest rate is assumed to be 6 %. Costs for district heat production is estimated to be 32.3 EUR/MWh, costs for electricity 67,7 EUR /MWh (same cost is used for both production and distribution, 1 SEK = € 0.11; 1 DKK = € 0.13).

The economy of the system is not exclusively dependent on the network system, but also, for example, on the ground conditions of the development area, the efficiency of planning and administration as well as the business cycle for contractors. The aim of this cost analysis is to give means to compare the economy of various systems relative each other. This study focuses on the economy of a variety of net systems, using costs for different pipe types and dimensions, where average material, planning and construction expenses are included in the price.

Damage to the system (leaking joints, broken pipes or parts) can cause distribution losses, necessitate costly repairs as well as leading to inconvenience for the heat customers. These costs are not taken into account in this study, as these damages more often depend on poor construction and/or planning and are not system dependent.

Table 6.2: Parameters used in the system cost calculations

General parameters (applies to all system applications)		
Heat cost	32	€ /MWh
Electricity cost	68	€ /MWh
Interest	6 %	
Annuity	8.72 %	
Depreciation time	20	years

6.2.3 Piping

The costs for piping/trenches are taken from the Swedish pipe system cost catalogue (Swedish District heating, 2007) - average prices for development areas. This means that they are not the lowest costs possible, but neither the highest possible costs; there are examples of district heating companies that manage to construct distribution nets at still lower costs. See also Appendix 2 for further cost examples.

The Swedish pipe system cost catalogue mentioned above contains prices for single and twin steel pipes only. For PEX pipes, the costs were adjusted by using data from a report by Zinko, et al (1999).

For systems including alternative types of pipe (EPSPEX, triple pipe), the costs are adjusted with a factor found in reports on these pipes (see also sections 6.3.4 – 6.3.7).

6.2.4 Other components

Costs for other components used in the systems are taken either from Swedish catalogue prices or from field experience (Table 6.3).

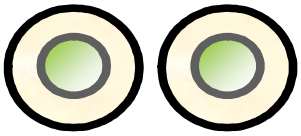
Table 6.3: Components costs used in the spreadsheet calculations

Component	***Temperatures [ºC]***	***Power [kW]***	***Cost [€]***
HEX (Domestic hot water)	65/22-55/10	40	600
Prefab sub central	100/63-80/60 and 65/22-55/11	18/33	1 100
Hot water storage tank	65/22-55/10		904
Remote metering			110
Heat meter			165
Booster pump			238
Work			
Piping/installation work (in substation)			1 430
Electric work (for meter, counter)			154

6.3 System solutions

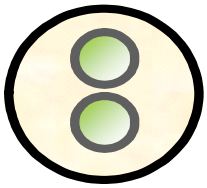
The pipe technologies described here include both classical standard design and new pipe solutions described in more detail in Chapter 5.

6.3.1 Traditional single pipe connection



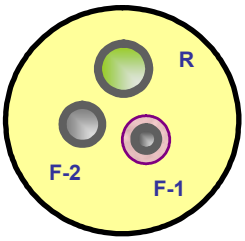
Traditionally, most district heating systems have been built with two single pipes; one supply and one return pipe. The most common piping material is steel, with polyurethane insulation and high density polyethylene jacket. The main advantage of using single pipes has been that it is a well-proven technology, which leads to a reliable (or at least predictable) system.

6.3.2 Twin pipe connection



Twin pipes can be made of steel, copper or PEX, with the feed and return pipe in the same jacket. The heat losses from twin pipes are lower than from single pipes with the same dimensions. In addition, twin pipes in small to medium dimensions (up to DN 100) are usually less expensive to install than single pipes. Though the technology for twin pipes is relatively new, it is now well-known and as available as single pipe systems in many countries.

6.3.3 Triple pipe connection



F-1:First prority forward pipe
F-2:Second priority forward pipe
R: Return pipe

For more details, see chapter 5.

Since there are no triple pipes currently on the market, no actual investment costs are available for the system. According to Bøhm and Kristjansson (2005), the investment cost for triple pipes is 21 % lower than the cost for traditional pipes[2]. Thus, in the system cost model, the cost for the triple pipe is assumed to be 79 % of the cost for traditional pipes.

The heat loss for the triple pipe is calculated by means of heat loss equations and U-values from Bøhm and Kristjansson (2005). Although this system probably

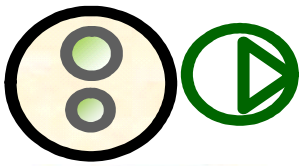
[2] Triple pipe with dimensions 15/18/20/105 (F-1/F-2/R/insulation) compared with pair of single pipes dimensions 25/77.

requires more advanced control strategies than the traditional system, this additional cost is hard to estimate and is thus neglected in the cost analysis.

Note that in the cost analysis model, only the service pipes are replaced with triple pipes; distribution pipes in the triple pipe system have the same type and dimensions as in the traditional twin pipe system.

6.3.4 Twin + booster pump

Another way of decreasing the pipe dimension (and thus the heat loss) is to use a booster pump. This way, the pipes can be smaller and when there is a need for more heat supply, the booster pump starts up and increases the flow. With this solution, the supply pipe can be reduced 2 dimensions and the return pipe 1 dimension. This system requires a booster pump in each customer station.



6.3.5 Twin + hot water tank

Although the domestic hot water (DHW) demand only represents a relatively small part of the total energy load, there can be large instantaneous heat loads when hot water is used by the customers. To avoid dimensioning the service pipes to meet the instantaneous heat fluxes caused by DHW tapping, a hot water tank can be installed in the customer station Figure 6.1 and Figure 6.2. This will make it possible to use smaller distribution pipes.

In summertime, when there is no heating demand, the district heat can be pulsed out once or more times a day to load the hot water tanks and the distribution net can be "off" the remaining time[3]. This will reduce heat losses in the distribution net, but the cost of installing a hot water tank is substantial and there will also be some heat losses from the tank.

In previous storage tank installations, there has been a problem with high return temperatures in the net, but if the DHW storage is properly installed, it can even lower the return temperature.

In areas with low heat density it may still be worth the extra investment for hot water tanks as the heat losses from the pipes get more critical with long distribution nets.

Figure 6.1: Substation with hot water tank and heat exchanger for radiator system

In the system cost analysis, a distribution net with storage for DHW for each customer is analysed. Heat is assumed to be distributed continuously to the tank at a relatively even rate (8 kW). The space-heating load will then be added to the DHW load. The cost for the hot water tanks are added to the total installation cost and the heat loss from the tank is also taken into account[4].

6.3.6 Shallow burial piping

A great part of the installation cost for a DH network is the excavation cost. Traditionally the trench is about 50 cm deep. If the pipe is going to be situated under a road, there will be a need to protect the piping from being damaged by traffic. Pipes in more undisturbed areas, though, can be placed at shallower depths, which will reduce the excavation cost substantially. The heat losses from these pipes will be slightly higher, though. A cost analysis was performed for a piping depth of 30 cm.

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[3] This method is not analysed in this study, however.

[4] During the heating period, the house is assumed to benefit from the heat loss from the tank. Only heat losses in summer are included in the cost analysis.

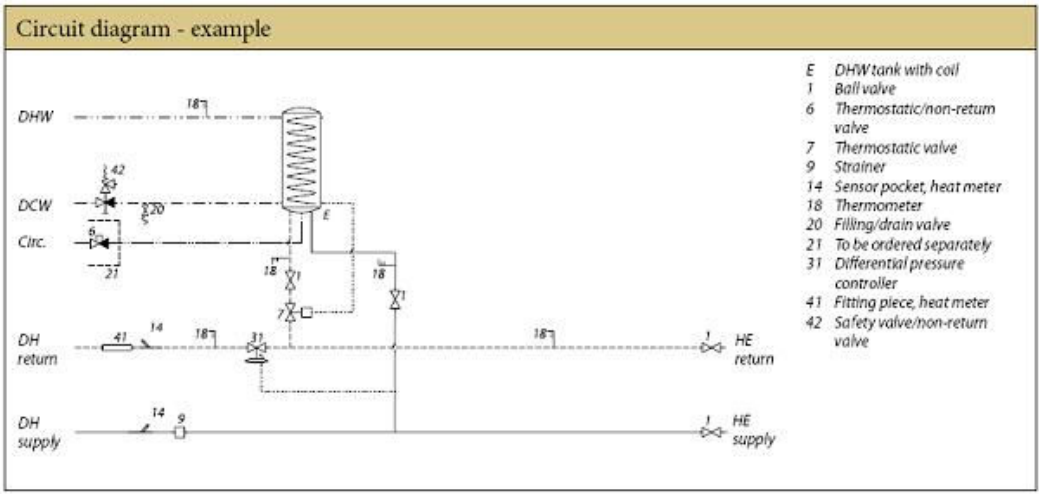

Figure 6.2: Schematic of substation for single-family houses with hot water tank and direct connected radiator system

6.3.7 EPSPEX

EPSPEX is a flexible system for heat distribution where pipes made of PEX are placed in insulation blocks of extruded polystyrene, EPS; two or four pipes in each block, see Figure 6.3, Figure 6.4a and 6.4b. If desired, the system could easily be adapted to three pipes. The investment cost is usually lower than for traditional systems and heat losses are also lower. This system has been used for district heating in Trelleborg, Sweden, where the pressure and temperature in the distribution system is low enough to permit the use of PEX pipes. In Trelleborg, a four-pipe district heating system has been built, with direct connection of DHW and heat exchangers for the radiator systems. That system has not been in use long enough to evaluate its performance (only since the spring of 2007). Other areas of use have primarily been in secondary distribution nets in residential houses, schools, dormitories, farms and hotels.

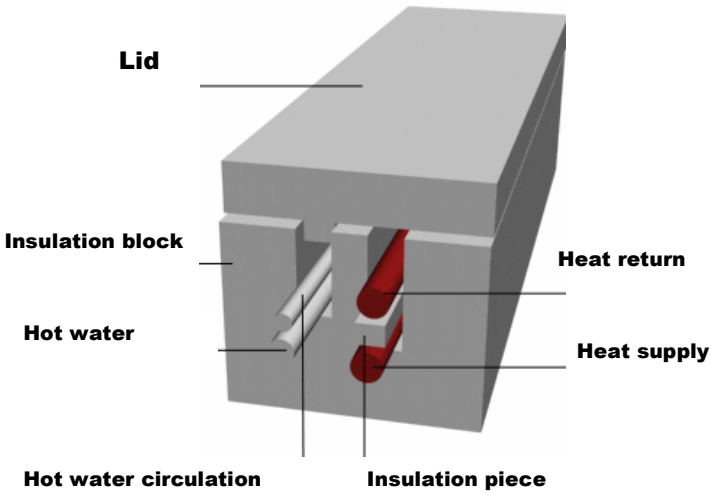

Figure 6.3: EPSPEX pipe system – schematic

The EPSPEX system used in the system cost analysis is a two-pipe system, as described by Gudmundson, (2005). Results from the project reported show that the installation costs for EPSPEX were 15 % lower than for a traditionally built network with twin pipes. The heat losses were, in addition, shown to be 35 % less than for a typical twin pipe system. In the model, the installation costs used are thus the cost for twin pipes (insulation class 2) multiplied with 0.85. The heat losses from the same pipes are multiplied with 0.65 to approximate the EPSPEX heat losses.

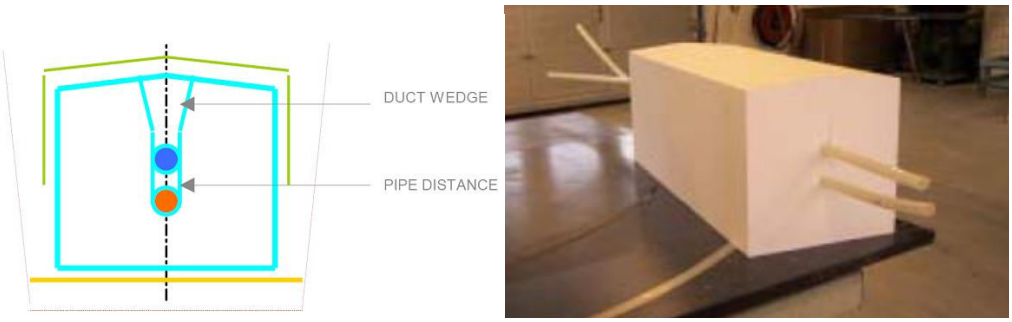

Figure 6.4 : a) EPSPEX pipe with two pipes. *b) Module of Two-pipe EPSPEX system*

6.3.8 House-to-house

Traditionally, distribution pipes are placed under or nearby streets, and service pipes are drawn from there to the houses. With house-to-house connection, distribution pipes are drawn closer to the houses, with only short service pipes (Figure 6.5). This method requires placing pipes in the ground of private properties as a rule and is probably best suited for new developments where all houses are connected to district heating. By connecting house to house, the total length of the network can be substantially reduced, thus reducing both installation costs and heat losses. Although, in some house-to-house connections, district heating pipes are drawn through houses (in basements or under floors), this is not done in the system analysed in the cost model. Some district heating companies have had trouble with distribution pipes inside private homes, especially when repairs have to be made. In this study, it is assumed that no additional cost is charged for the district heating company's right to place distribution pipes in the lawns of private properties.

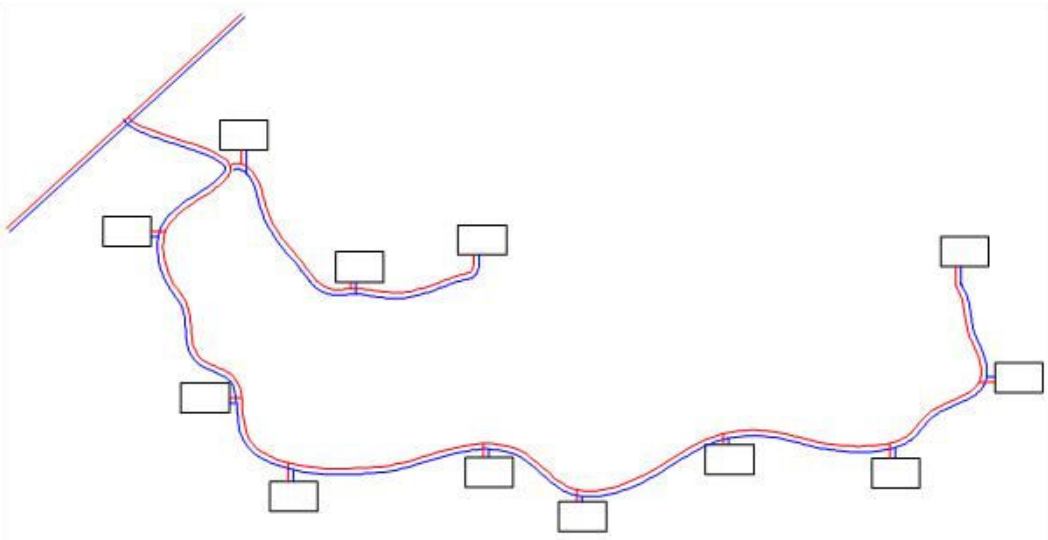

Figure 6.5: House-to-house connection, schematic

6.4 System applied for Neidonkallio conditions

Conditions for Neidonkallio[5]

$T_{forward}$ = 87°C (Yearly average supply temperature)

T_{return} = 43°C (Yearly average return temperature)

T_{out} = 5°C (Yearly average outdoor temperature)

Number of houses in Neidonkallio: 30

6.4.1 General

The existing network in Neidonkallio is a traditional single pipe network using series 3 insulation with customer substations (which is the normal case in Finland). The total pipe length is 2502 m. When the net was dimensioned, a connection rate of 100 % was anticipated. In reality, about 85 % of houses were connected to the district heating network. The pipe dimensions are therefore larger than what would be necessary. Furthermore, allowances have also been made for a possible expansion of the distribution net as well as a general safety margin was added. Consequently, the pipe dimensions in the net are larger than needed. This dimensioning will affect all other solutions also, with the exception for the slim dimensioning system described in sect. 6.4.5.

Even though the pipes are somewhat over-dimensioned, the actual parameters used on-site in Neidonkallio are the lengths and dimensions used in the cost analysis. The same lengths and dimensions are used for all systems analysed, with exceptions for the slim dimensioning system and the house-to-house system, sect. 6.4.6. Some of the systems have smaller service pipes, though, which have been specified in the system descriptions.

6.4.2 Single pipes, traditional connection with customer substation

The traditional connection method with single pipes was analysed for steel pipes with series 1, 2 and 3 insulation. Each house was connected via customer substations (which is the normal connection method in Finland).

6.4.3 Twin pipes

The same basic system as sect. 6.4.2 was analysed, with the only change being a switch from single pipes to twin pipes. Insulation class 2 was used (All commercially available pre-insulated twin pipes are with series 2 insulation.).

6.4.4 Low depth piping

The same basic system as described in section *6.4.2* was analysed, but with twin pipes, placed at low depth (30 cm), using insulation series 2.

6.4.5 Slim dimensioning system

This is a strategy deviating from handbook-design: A system with the same pipe lengths and connection method as the system described in section 6.4.2, but with optimized (smaller) dimensions, was analysed with twin pipes, series 2 insulation and single pipes, series 2 and series 3 insulation. The pipes were optimized to supply heat to cover the maximum design heat demand without exceeding the acceptable pressure drop for a pipe of 1.5 bar/km.

6.4.6 House-to-house

The cost analysis was made with twin steel pipes, series 2 insulation. By introducing the house-to-house method, pipe length was reduced from 2502 m to 1575 m.

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[5] Yearly energy is about 1800 MWh.

6.4.7 EPSPEX

The cost for the EPSPEX system is calculated for a two pipe system with PEX pipes imbedded in 300 x 300 mm EPS blocks. The same lengths and dimensions for pipes were used as for the system described in section 6.4.2. Although the distribution system in Neidonkallio is a high temperature and high pressure system, the economy of the EPSPEX is calculated with the current temperatures in order to make the comparison as fair as possible. If an EPSPEX system were to be applied in reality, the temperature and pressure levels would need to be lower, since the materials in the EPSPEX system cannot endure high temperature and pressure (maximum 6 bar and 85°C).

6.4.8 Triple pipe

For the system cost analysis, the lengths and dimensions of distribution pipes for the triple pipe system are the same as for the basic case described in section 6.4.2. Twin pipes are used for all distribution pipes. The service pipes are all triple pipe with dimensions 15/18/20 (mm) [F1/F2/R], cf. Chapter 5.

6.5 Results Neidonkallio

The annual costs for the various systems in Neidonkallio are presented in Figure 6.6. The total yearly costs for the different solutions in the Neidonkallio network varies between €39 000 and €69 000.

The first four columns represent the traditional system with different (standard) pipe types and insulation. The most cost effective of those is the twin pipe system (series 2 insulation). The total costs for single pipe systems with series 1 and 2 insulation are essentially a tie (although the ratio between installation cost and heat loss cost is not the same). The highest total cost has the existing system with single pipes, insulation series 3. Although the heat losses are lowest in this system, the higher investment cost is not paid for within the 20 year period. Even though cost analyses are not done for all pipe types in the other system solutions, the same correlation between costs and pipe types would be found. This can be seen with the slim dimension systems (twin series 2, single series 2 and 3) and house-to-house system (twin series 2, single series 3).

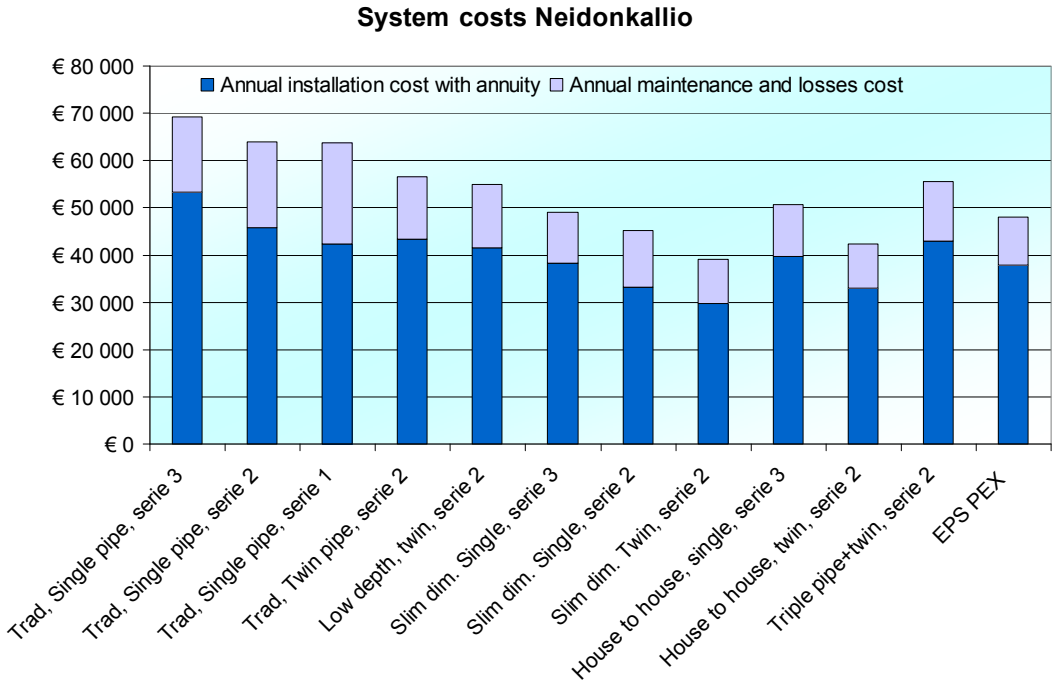

Figure 6.6: Comparison of total costs (installation and operation) of different system solutions – Neidonkallio

The "slim dimension" system with twin pipes had the lowest total cost; the installation cost was lower than any of the other systems, and operation costs were in parity with the house-to-house

system. The house-to-house system has a significantly shorter network length than the others (63 % of original length), which is the main reason for its lower costs. The most expensive system in the analysis is the system currently used in Neidonkallio: Single-pipes with series 3 insulation. Even though the EPSPEX system was calculated with the same (oversized) pipes as the traditional systems, they have a lower cost than those. With better-suited dimensions, the system would have an even lower total cost.

6.6 Diffusion barrier

District heating pipes are usually insulated with rigid foam, where cyclo-pentane gas that has favourable insulating properties fills the cells of the polyurethane foam. This keeps the heat losses low. Measurements have shown, though, that with time, the cyclo-pentane gas diffuses through the polyethylene jacket, which impairs the pipe's insulating capacity. To prevent this from happening, the pipe can be provided with a diffusion barrier. Pipes with diffusion barriers are now starting to become popular. The technique is not yet available for all types of pipe, but will probably be so in the near future. In this study, we have assumed a diffusion barrier on all pipes.

Figure 6.7 illustrates the difference in annual heat loss for a typical twin pipe system in Neidonkallio with or without a diffusion barrier. The heat loss with diffusion barrier is 7 % lower than the heat loss without the barrier (averaged over a 20 year period).

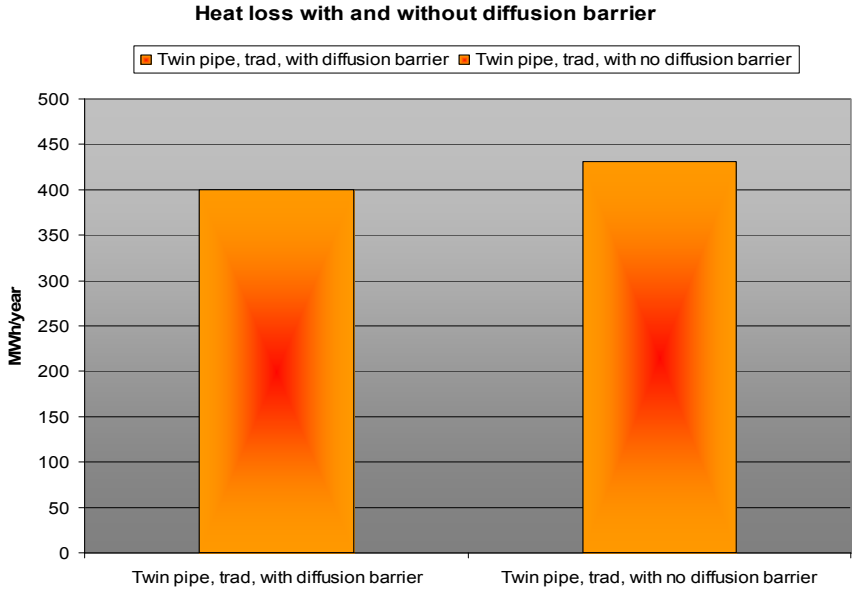

Figure 6.7: Comparison of yearly average heat loss between two traditional twin pipe systems (Neidonkallio conditions); to the left with diffusion barrier and to the right without diffusion barrier.

6.7 Application for Nykøbing/Falster

Conditions for Nykøbing[6]

$T_{forward}$ = 75°C (Yearly average feed temperature)

T_{return} = 40°C (Yearly average return temperature)

T_{out} = 9°C (Yearly average outdoor temperature)

Number of houses in Nykøbing: 16

[6] Yearly energy is about 324 MWh

6.7.1 General

The existing network in Nykøbing was originally a traditional single pipe network using series 1 insulation with direct connection (which is a normal case in Denmark). The total pipe length was 559 m. In a project together with Logstor, the municipality of Guldborgsund has recently replaced the single pipe system with a twin pipe system. The new system has a total pipe length of 575 m. Pipe length and dimensions are presented in Table 6.3:

Table 6.3: Pipe dimensions

Pipe dimensions Peter Freuchensvej						
OLD SYSTEM (Single pipes)				**New System** (Twin pipes)		
Steel pipes				***Steel pipes***		
Inner diameter	Dim	Length		Inner diameter	Dim	Length
[mm]	[DN]	[m]		[mm]	[DN]	[m]
ø34	25	200.3		ø27	20	8.4
ø40	32	29.5		ø34	25	55.1
ø60	50	12.5		ø42	32	15.4
ø76	65	118.7		ø48	40	71.0
ø89	80	90.3		ø60	50	116.8
Pex pipes				***Pex pipes***		
Inner diameter	Dim	Length		Inner diameter	Dim	Length
[mm]	[DN]	[m]		[mm]	[DN]	[m]
ø22	22	96.5		ø16	16	276.3
ø28	28	11.1		ø20	20	31.5
Total pipe length		558.6		Total pipe length		574.6

6.7.2 Old single pipes

Cost analyses were performed for the old single pipe system (traditional connection method with series 1 insulation). It was also assumed that the old single pipes had a higher heat transfer coefficient than the newer pipes. The houses were connected directly to the net, with heat exchangers for domestic hot water. Installation cost was calculated with the same prices as for the new systems and with the same timeframe. The total pipe length is 559 m.

6.7.3 Twin pipe

The new twin pipes system was also analysed. In this scenario as well, the houses were connected directly to the net, with heat exchangers for domestic hot water preparation. The network in Nykøbing was replaced by twin pipe network, which by default, has series 2 insulation. The pipe dimensions were generally smaller in the new version of the net. The total pipe length is 575 m.

6.7.4 New single pipe

Cost analyses were performed for a hypothetical single pipe system with the same pipe lengths and dimensions as the new twin pipe system

6.7.5 Twin + hot water tank

A distribution net with a twin pipe system (slightly smaller pipe dimensions than the traditional twin pipe system), combined with hot water storage for domestic tap water in each connected building was analysed.

6.7.6 Single + hot water tank

A distribution net with a single pipe system (slightly smaller pipe dimensions than the traditional twin pipe system), combined with hot water storage for domestic tap water in each connected building was analysed.

6.7.7 Twin + booster pump

A distribution net with a twin pipe system (slightly smaller pipe dimensions than the traditional twin pipe system), combined with booster pumps in each connected building was analysed.

6.7.8 Triple pipe

A system with the same pipe lengths and dimensions as the twin pipe system, but with the service pipes replaced by triple pipes, was analysed.

6.7.9 EPSPEX

The cost for the EPSPEX system is calculated for a two pipe system with PEX pipes imbedded in 300x300 mm EPS blocks. The same lengths and dimensions for pipes were used as for the twin pipe system.

6.8 Results Nykøbing

The result from the cost analysis can be seen in Figure 6.8, where the annual cost for each system is presented. On average, the installation costs represent about 80 % of the total annual cost for the distribution nets. Depending on which system is analysed, the proportion of the investment cost is between 71 % and 81 %.

6.8.1 Correlation with real costs

The twin system is cheaper to install and also has lower operating costs than the single pipe system. The real investment cost for the new twin pipe system was € 86 840 when it was installed. The total calculated installation cost in the analysis model is € 85 617. This cost is including heat exchangers and work in customer substations, a cost that is not included in the € 86 840. The cost for only the pipe installation in this model is calculated to be € 46 273. In the model, a new development area is assumed, while in the actual case in Nykøbing, the installation work was performed in an existing area (with an old distribution net to replace). Since the cost for excavation and civil work (including restoring asphalt) amounted to approximately 60 % of the total installation cost, this explains the divergence between the real and calculated value.

6.8.2 Old network compared with new

The new system is more cost efficient than the old, even when comparing with the same type of pipes, see Figure 6.8. This is due to improved pipes as well as a better (slimmer) dimensioned net. Both investment cost and heat losses are reduced with the new system. If the comparison were to bee between keeping an old network (for which the investment would have been essentially paid off; thus leaving the investment cost as close to zero) or replacing it, the heat losses would still be high from the old system, but the savings on operational costs for the new system would have to be significant to justify the investment. There might be other considerations, however; such as poor condition of the old pipes and/or components, which would necessitate a replacement.

6.8.3 EPSPEX

EPSPEX had the lowest total cost of the analysed systems. Both total installation cost and annual losses were lower than any of the other systems. It should be noted, though, that the computer data was based on a report made from a single application instead of statistics from several nets. Since PEX pipes are already used in Nykøbing and the EPSPEX system is available on the market, this solution could easily be implemented in a similar net, where the system temperatures and pressures will allow.

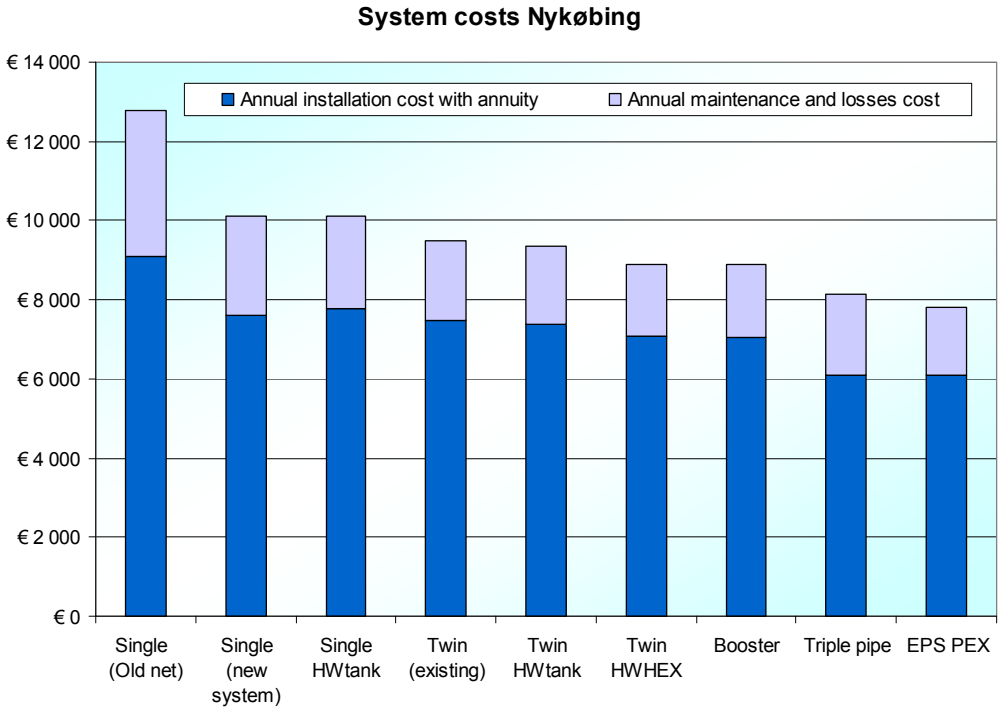

Figure 6.8: Comparison of total costs (installation and operation) of different system solutions – Nykøbing /Falster

6.9 Discussion

6.9.1 The importance of accurate dimensioning

In the Neidonkallio case, the installed pipes are larger than what is needed in order to transport the required heat without exceeding recommended pressure drop (1.5 bar/km). This was also the case in Nykøbing before replacing the old single pipe system with a more optimally sized twin pipe system. Oversized dimensions are also common in many other nets, where dimensioning often has been made with "rules of thumb". In some cases installing over-sized pipes was justified, for instance when there are plans for a future extension of the distribution net. But, as we have seen in the calculations, there is a lot to gain by keeping the distribution net as slim as possible. It is certainly a good idea to at least keep the dimensions of the service pipes to a minimum (which wouldn't affect a potential future extension), possibly in combination with booster pumps or hot water storage.

6.9.2 One two or more pipes in the same jacket

Even a five-year-old child will know that it's warmer to wear mittens than gloves. Even though that is a bit simplified, the principle stays the same; the total heat loss will be reduced with two or more district heating pipes within the same casing. Heat loss from the pipes will partly be benefited by the other(s) and the total surface area exposed to surrounding ground will be smaller than for separate pipes. The installation work will also be more cost effective with one pipe to put in the ground instead of two or more. Twin pipes might be more expensive to purchase, but the total cost is still lower (for small to medium sized pipes).

6.9.3 Triple pipe

Triple pipes are not available on the market as of yet, but provided that they are accompanied with appropriate control, they have a potential to provide cost effective distribution. The triple pipe system will give reduced heat losses, not only because of three pipes sharing one jacket, but (as with booster pumps and hot water tanks) by reducing the pipe diameters. The triple pipe system will not require a booster pump or hot water storage and therefore has a lower installation cost than

those options. There will, however, be a need for a special control device for regulating the flow of the second feed pipe. *Triple pipes are not available on the market at this point; they only exist as prototypes.*

6.9.4 EPSPEX

The EPSPEX system can be used with two, three or four pipes, as needed. This system has good insulating qualities and is uncomplicated to install, resulting in good economy for the system. This is a product, which is commercially available (currently marketed mainly in Sweden and Denmark) and suitable for systems with operating temperatures below 85°C and pressures below 6 Bar. Since it is relatively new on the market there aren't very many distribution nets in use yet to draw experience from. Those who are using it[7], seem to be content this far though.

6.9.5 Shallow burial piping

By placing the district heating pipes at lower depths than traditionally done, installation costs can be reduced. The heat loss will be somewhat higher, but negligible compared to the cost that is saved by this method. This method can be combined with other system solutions (twin pipe, house-to-house, EPSPEX for example).

6.9.6 House to house - PEX

By connecting with the "house-to-house"-method, pipe length can be substantially reduced (in the case of Neidonkallio; from 2502 m to 1575 m). This system depends on the availability of the premises where the pipes are to be drawn. Often the district heating companies are reluctant to use private properties, as they would then have to arrange for easements. Given an area where the connections could be made without too much "red tape" this could be a sound system solution.

6.9.7 Booster pump

A booster pump can make it possible to use smaller dimensions for the pipes, which reduces heat losses in the system. Because of the smaller pipe dimensions, the installation cost will be lower than for the traditional twin pipe system; even though there is an additional cost for the booster pump.

6.9.8 Hot water tank

A hot water tank in the building also makes it possible to use smaller dimensions for the service pipes and possibly for the distribution pipes. This will reduce heat losses in the distribution system. The installation cost will be higher than for the traditional twin pipe system, even though the pipes are smaller, since the cost for a hot water tank must be included. The tank also has heat losses that must be taken into consideration. The heat loss from a tank will be the same regardless of the system load density. The portion this heat loss will take of the total is therefore smaller in areas with low heat demand density. Whether the return temperature will increase or decrease when a hot water tank is installed, depends on the degree of sophistication of its control system.

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[7] Trelleborg Energi (Sweden) is using EPSPEX in part of their distribution net.

7 Increased use of district heat instead of electricity in households

Summary:

The objective of this chapter is to investigate how the load of detached houses can be increased, partially by shifting the energy use from electricity to district heating and partially by increasing the customer's comfort. The chapter describes methods to increase utilisation of district heating that were demonstrated in a project in Gothenburg, Sweden. It describes also, how the total load would change, if some of these loads would be used consequently in row houses in Neidonkallio. Finally, the chapter presents some ideas of how to introduce novel district heating applications.

7.1 Why new heat loads?

The main intention is that the district heating application should be reconcilable with the overall goal of district heating, i.e. of being an environmental friendly energy system and not seriously increase the costs of basic energy purchase for the customer (however, increased cost will occur in some cases due to increased comfort).

The problem related to the heat distribution in low density district heating is twofold: First at all, the total annual heat load is relatively small and therefore there is a lessened possibility for depreciating the investments in the heat distribution system. Secondly, the heat demand during the summer time is low, which makes heat distribution difficult to operate effectively. This situation is especially true in the Northern countries, which have large differences between the summer load and the winter load in district heating networks. The Figure 3.4 shows the heat load and heat losses measured for the year 2004 from an area with 103 detached houses in Växjö, Sweden, constructed between 1995 and 2000.

From Figure 3.4 it can be seen, that the relative heat losses in the summertime can reach about 40 % in new areas and are reportedly still higher in areas with older systems. Hence, projects and techniques are of interest that can increase the load without impairing the sustainable use of district heating.

Interesting techniques are primarily techniques where electricity can be replaced by district heating. Under European presumptions, we can namely conclude that the marginal electricity production stems from coal condensing power and hence a decreased use of electricity will have a relatively strong influence on the emission of CO_2 and the climatic consequences related to it. This is also true, but to a lesser degree, if the marginal electricity in the future is produced by gas fired combined cycle power plants.

7.2 New loads saving electricity

7.2.1 White goods for dishing, washing and drying.

One class appliances that immediately comes to mind in district heating connected households are the machines using hot water for cloth washing, dish washing and cloth drying purposes. These machines are today in private households in Europe normally connected to the cold city water and all heat is provided through electrical heating. Some types of dishwashers are, however, equipped with both hot- and coldwater connections, which means that a part of heat could be provided - at least in principle - via domestic hot water. Such possibilities exist also for washing machines, but we have only found very few types of machines for the private sector that have this possibility. Tumble driers need normally higher temperature for the drying process and all machines for the private sector we have found were electrically heated.

Because of the widespread use of these appliances and the use of district heating (and also renewable energies like solar energy and pellets), it is largely an issue of high exergetic and environmental significance to investigate the possibility of using energy from hot water for the water heating process instead of electricity in these machines.

The advantage and at the same time dilemma of modern (dish- and cloth washing) machines are that they are designed for *low water consumption*. That means that the amount of process water is so low that there is not much energy available from it to provide the necessary energy for heating the goods to be cleaned in the machines. Therefore, if a high amount of energy should come from hot water, the heat must be transferred via a *heat exchanger* and cannot be taken from the domestic hot water consumed directly in the process. This also holds, of course, for the tumble-drier because hot water is not at all consumed in drying process. That means that a complete new machine construction is necessary which includes a *heat exchanger* providing heat that can be taken from a hot water circuit instead from the electrical heater inside of the machine. However, the electrical heater might be kept in place for the reason of back-up and in the case of high desired process temperatures in washing machines and tumble driers.

In The Netherlands and in Sweden, pilot projects using these types of machines have been carried out in the past (Hof (1996), Zegers & Molenbroek (2000), Persson (2007), Zinko (2007). In The Netherlands compact flat plate heat exchangers have been used in all three types of machines in a project carried out at the end of the 1990s. In the Swedish project, coaxial pipe heat exchangers have been used and built in standard machines. In the following, we will refer to results from the Swedish pilot project installed in Gothenburg and from the Dutch project with regard to the tumble-drier.

<u>Heat-connected dishwasher and washing machine</u>

The heat driven dishwasher and washing machine were initially developed in a doctoral thesis (Persson, 2007). Both machines were analysed and field tested during this work but thereafter rebuilt for the pilot project in Gothenburg (Zinko, 2007).

The dishwasher is based on a household product from Cylinda (DW 20.1) and was rebuilt according to Figure 7.1.

The heat exchanger is a coaxial pipe made of two copper pipes (DN 28 and 22 mm, respectively). The pipe going to the upper spray arm is replaced by the heat exchanger and the process water is pumped through the inner pipe of the heat exchanger (length 1.47 m). The flow rate of the internal pipe is 0.6 kg/sec. The outer pipe is connected to the heating medium (in this case a secondary circuit connected via a plate-heat exchanger to district heating). The flow rate in this pipe is 0.03 kg/sec. The flow is controlled by a solenoid valve SV1calling for the district heating water. If by some reason this water is 5°C lower than the set point value, the flow stops and the electrical heater is activated.

As a washing machine, a Cylinda WM 33A has been used. The design principle and flow rates were similar to that of the dishwasher, but the heat exchanger (length 1.3 m) was placed outside the machine and an extra water pump (P2) is used for circulating the process water. This pump starts whenever heat is called for. In Figure 7.2, the temperatures of process water and heating medium and the heating rate are plotted for a working cycle of both machines.

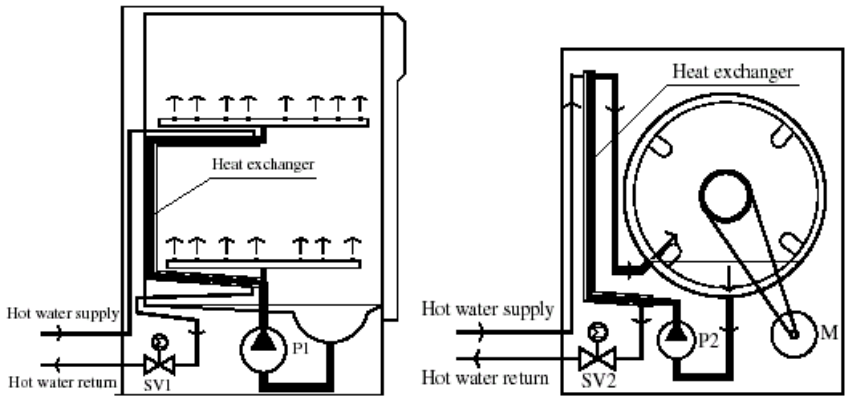

Figure 7.1: Connection scheme of the heat exchangers in dishwasher and the washing machine

The laboratory measurements were used to verify a modelling program (TRANSYS) that in turn thereafter allowed calculating the heat rates at different operating temperatures and operating modes of the machines. In Figure 7.3, the results of the simulation are summarised by comparing both the dish washing and cloth washing processes for machines using domestic hot water in contrast to using heating water for the process.

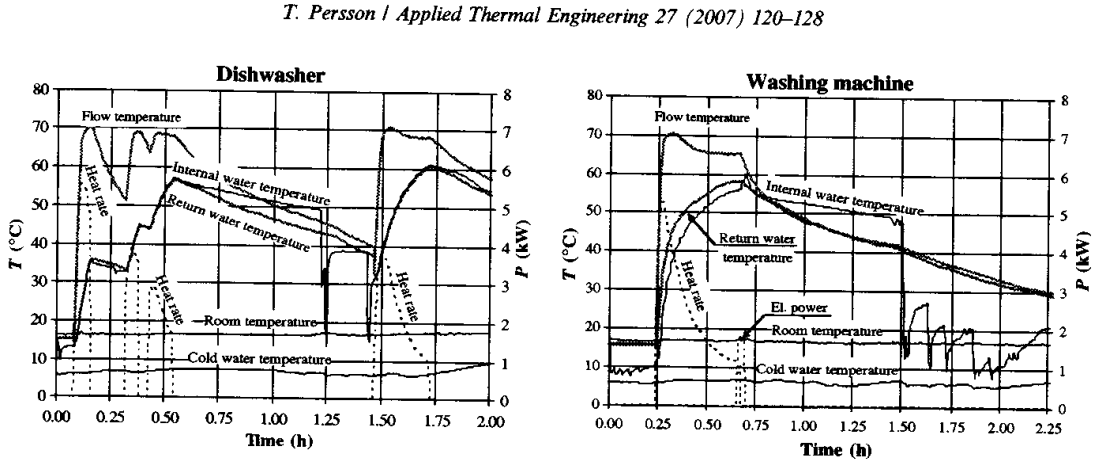

Figure 7.2: Laboratory measurements of temperature and heating rate for dishwasher and washing for the Cylinda machines (Persson 2007).

It can be seen from Figure 7.3 that hot water-fed dishing machines can, in the best case of high tap water temperatures (65°C), supply half of the process energy by means of the hot water supply and with "normal" temperatures (55°C) only one third of the needed energy.

In heat-fed machines with incoming heating water temperature at 70°C or higher, all heat can be supplied by the heating circuit, i.e. 78 % of the needed energy (the remaining is used by the electrical and electronic equipment of the machine). The total energy consumption for one dish washing cycle is 1.18 kWh.

In the washing machine, the amount of delivered heating energy is depending on the desired washing process temperature. At a normal washing temperature of 60°C, a machine fed with domestic hot water at 55°C can supply 33 % of the needed energy, and in case of a hot water temperature of 65°C, 60 % of the energy. When connected to district heating, at supply temperatures > 75°C, practically all heat can be supplied to the 60°C washing, which is about 77 % of the total energy use of 1.05 kWh for one washing. Of course, all heating needs for

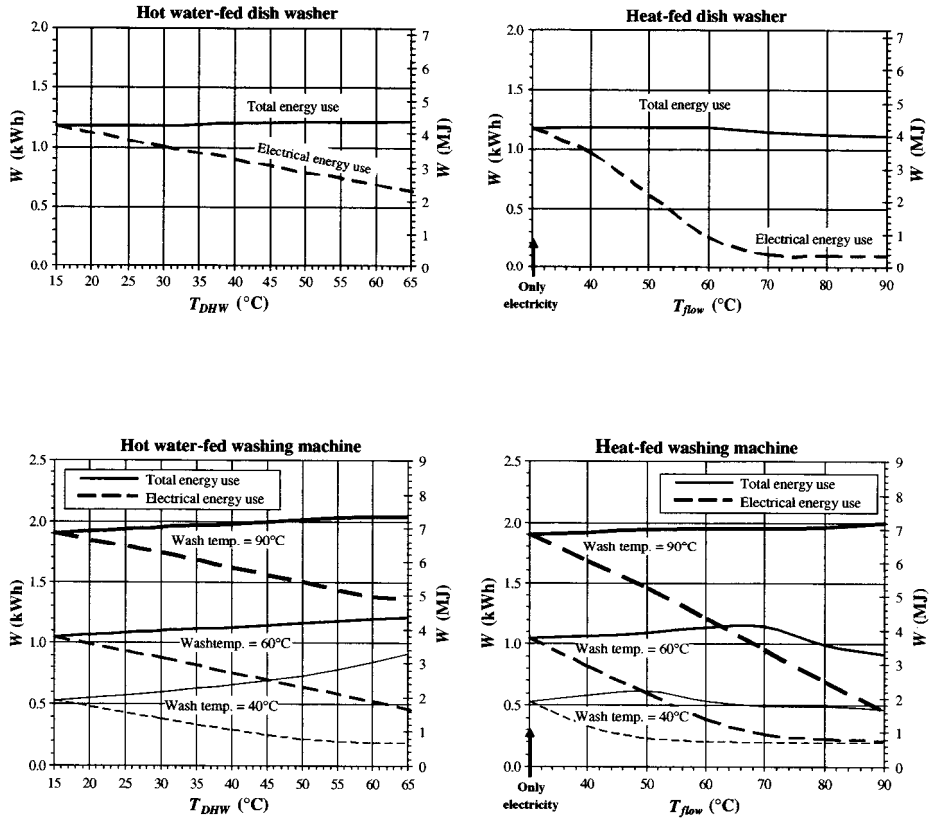

Figure 7.3: Simulated energy demand for hot water-fed and heat-fed dishwasher and washing machines as function of hot water temperature or district heating temperature for different operation temperatures. Both the heat supply and the electricity supply are indicated (Persson, 2007).

washing at 40°C can be applied (which is 0.3 kWh per washing, remaining 0.2 kWh operational electricity), but the heat delivery for a 90°C washing depends heavily on the supply temperature. At 75°C, about 1 kWh can be supplied by heat and 0.8 kWh must be supplied by electricity (for both operational energy and heating above the supply temperature).

Heat-Connected Tumble Drier

The only tumble-drier heat supply experiment for private households that we found is that of The Netherlands, see Figure 7.4.

In this condensing tumble-drier, a cross flow heat exchanger is providing the process heat. The heat-fed dryer is based on a Miele comfortline T559C. The machine was also modified by using a large condenser and larger fans for the drying air as well as the cooling air. (The machine was produced in a handful exemplars and one of the machines operates now in the Swedish demonstration project in Gothenburg).

The cycle time increased to 120 minutes (compared to normally 80 – 100 minutes in electrical machines). A solenoid valve opens for call of the district heating water. Electrical heating can be used as back-up. The DH flow rate is 0.025 l/sec at minimum 70°C DH supply temperature and the rated electrical power is 0.46 kW. When filled with 5 kg cotton cupboard dry laundry, the process will use 3.4 kWh heat and 0.77 kWh electricity.

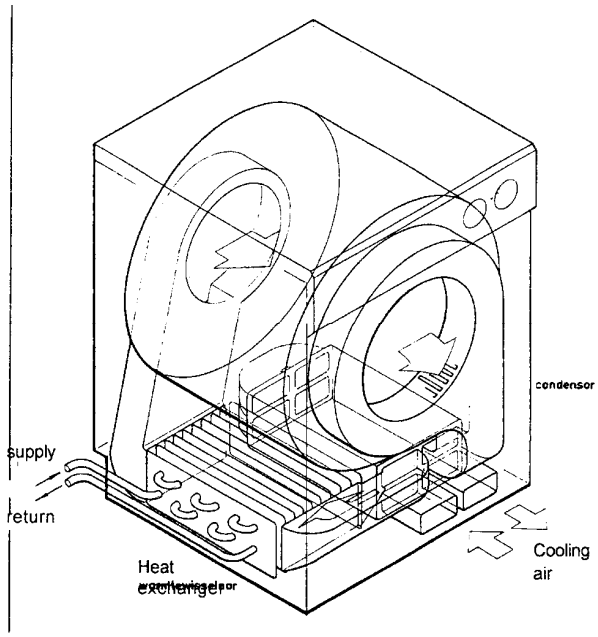

Figure 7.4: Drawing of the tumble drier developed in the Dutch demonstration project (Zegers-Molenbroek, 2000).

Model loads of appliances for simulations

For use in simulations models, we have used the available information from Figure 7.2 and 7.3 and information from Zegers & Molenbroek (2000), to establish 6-minute values energy model for the different machines. These models are further used in heat load calculations, see Figure 7.5 a-c.

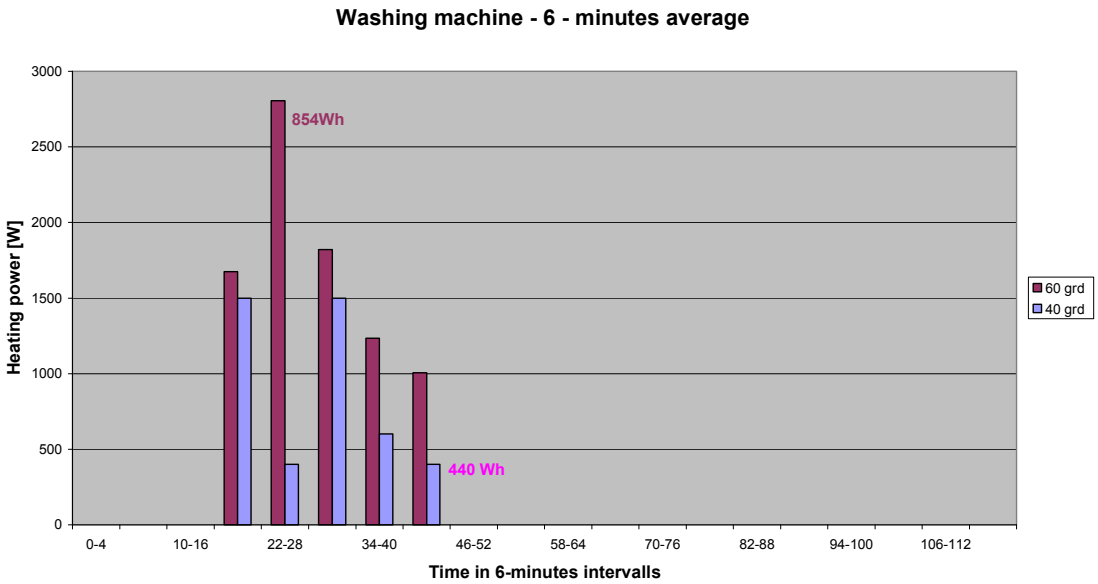

Figure 7.5 a

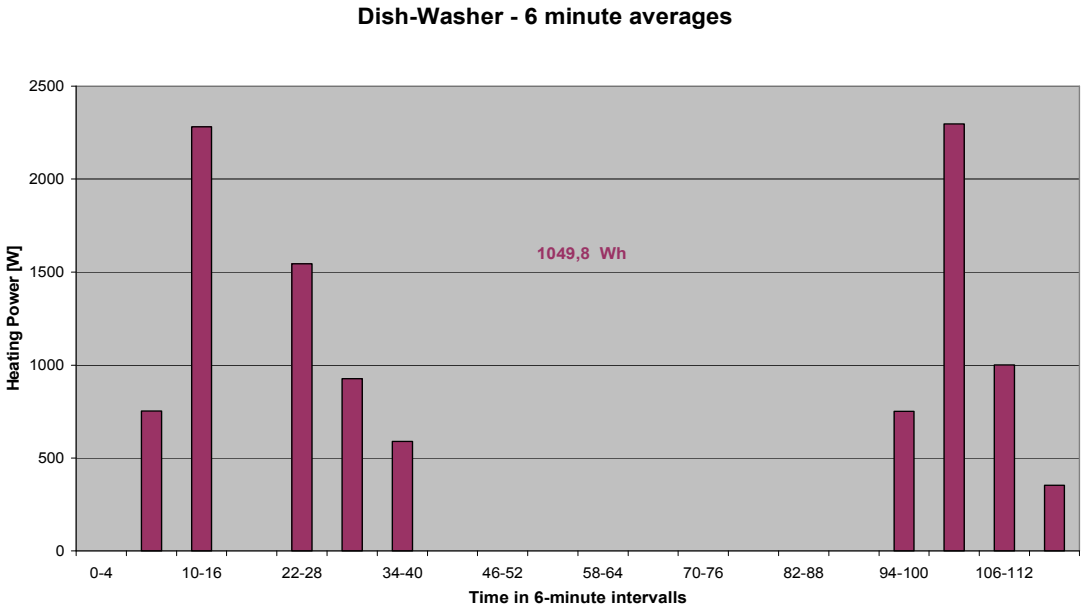

Figure 7.b

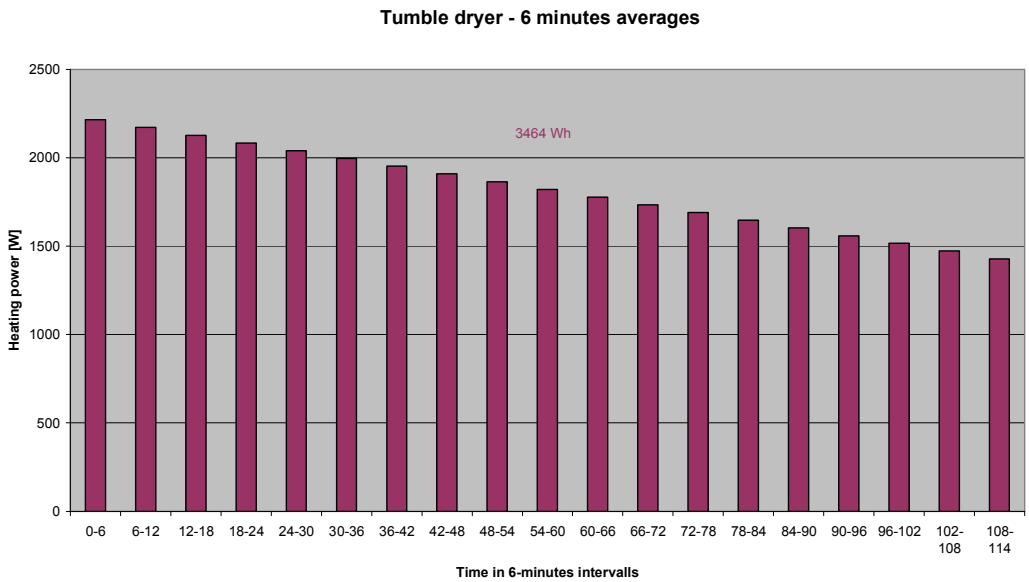

Figure 7.5 a-c: 6-minutes – model values for the three machine types to be used in simulation models.
The washing machine values belong to the washing process temperatures 60°C and 40°C respectively. The columns present the average power in Watt during each time interval (the corresponding energy is a tenth of this value in Watt-hours).

In Table 7.1, a summary for the total energy use of each machine is given. These values are slightly higher than typical values for state-of the art technique of 2004 (dish washing and cloth washing machines) and 1998 (Tumble drier) for the corresponding electricity only machine. This can be understood since piping and heat exchangers inside the machines introduce some extra losses.

Table 7.1: Presumed heat demand and electrical energy for one typical operating sequence for district heating-fed household machines. (Energy losses in feed piping not included).

	Electricity demand kWh	Heat demand kWh	Total kWh
Dishwasher	0.13	1.05	1.18
Washing machine 60°C	0.24	0.85	1.09
Washing machine 40°C	0.24	0.44	0.68
Tumble drier 70 % humidity	0.46	3.46	3.92

All the machines describe above could be (at least principally) applied in the households connected to the district heating market and thus replace an appreciable amount of electricity by low grade heat. By considering that the district heating holds about a 10 % heating share in Europe, it's apparent that it would be worthwhile for both the producers of appliances and the climate to further develop this technology.

7.2.2 Absorption Chiller

Another load, well suitable for district heating systems and especially contributing to times with lower loads, is *air-conditioning*. The conventional way to use air-conditioning in industrialised countries is to use electrically driven compression chillers. Such air-conditioning systems can be manufactured in any size from those suitable for small detached houses up to big office complexes. Another way, more interesting for the district heating market, is district cooling.

District cooling can be supplied either by a separate cooling network, as it is increasingly the case in several countries such as France, Sweden, Germany and the United States or by means of distributed absorption chillers fed by the district heating net. Usually (for economic reasons), heat driven air-conditioning applications are limited to chiller capacities above 100 kW per unit, leaving the market for small applications to the electrically driven systems.

However, especially in areas with low heat densities, heat-fed systems would be well worth considering, thus increasing the summer heat load. For this purpose, in detached houses and small multi-family buildings, heat-driven air-conditioning systems would be a very interesting product, if they were commercially available in sizes below say 50 kW heat input. For the time being, this is not the case. In the most cases, there are only prototypes available with costs that are far from economic levels (compared to the cost of electrically driven machines). Table 7.2 shows a survey of heat-driven, small-sized air-conditioning machines based on the absorption principle (water/lithium bromide or ammonia/water). Another possibility for the same purpose is heat - driven adsorption technology (f.i, water adsorbed and desorbed in silica-gel) but also this technology is not available in small capacities. (Table from graduate thesis by Fraile Fernández, 2007).

Table 7.2: Small capacity absorption chillers on the market or under development (May 2005).

Manufacturer/ R&D	Country	Capacity (kW)	Cooling-medium	Working pair	Driving Heat (ºC)	Cycle COP
PINK/Joanneum Research	Austria	10	Water	NH_3/H_2O	80	0.60
Yazaki	Japan	35	Water	$LiBr/H_2O$	87	0.71
SolarFrost	Austria	2	Water	NH_3/H_2O	80	0.89
IEAW	Germany	15	Water	$LiBr/H_2O$	85	0.7
ClimateWell AB	Sweden	10	Water	$LiCl/H_2O$	70	0.7
Phoenix	Germany	10	Water	$LiBr/H_2O$	72	0.82
Rotartica	Spain	4.5	Water	$LiBr/H_2O$	90	0.7
Rinnal/ Oska gas	Japan	6.7	Water	$LiBr/H_2O$	Gas-fired	1.2
Robur	Italy	15	Air	NH_3/H_2O	Gas-fired	0.9

As it turns out, the only commercially available machine is the Yazaki 35 kW machine. A couple of years ago, Yazaki had also a 10 kW (cooling) machine on the market, but for economic reasons, it was 2006 no longer available.

PINK - pilot ACM 6 kW

In the above-mentioned demonstration project in Gothenburg (Zinko, 2006), a pilot air-conditioning system was installed delivered by the company Pink-Energy in Austria (Figure 7.6). This machine is rated to 10 kW driving energy and 6 kW Cooling load production at an ambient temperature of 30°C and a dry cooling temperature at 33°C. Such a machine can well suite the normal cooling conditions in detached houses of Northern and Middle Europe and hence would fit the concept of use in areas with detached houses. Figure 7.7 shows the energy flows and the technical principals for such a machine. In the given case, the Coefficient of Performance (COP) in this system is 0.6, which is low compared to that of electrical driven compressor systems. In many cases, were the summer energy is a by-product from garbage incineration or from cogeneration plants, however, the low efficiency is not real a significant impediment. The nominal DH-supply temperature for the machine is 80°C.

Figure 7.6: Prototype of 6 kW (cooling) absorption chiller of Pink-Energy, Austria.

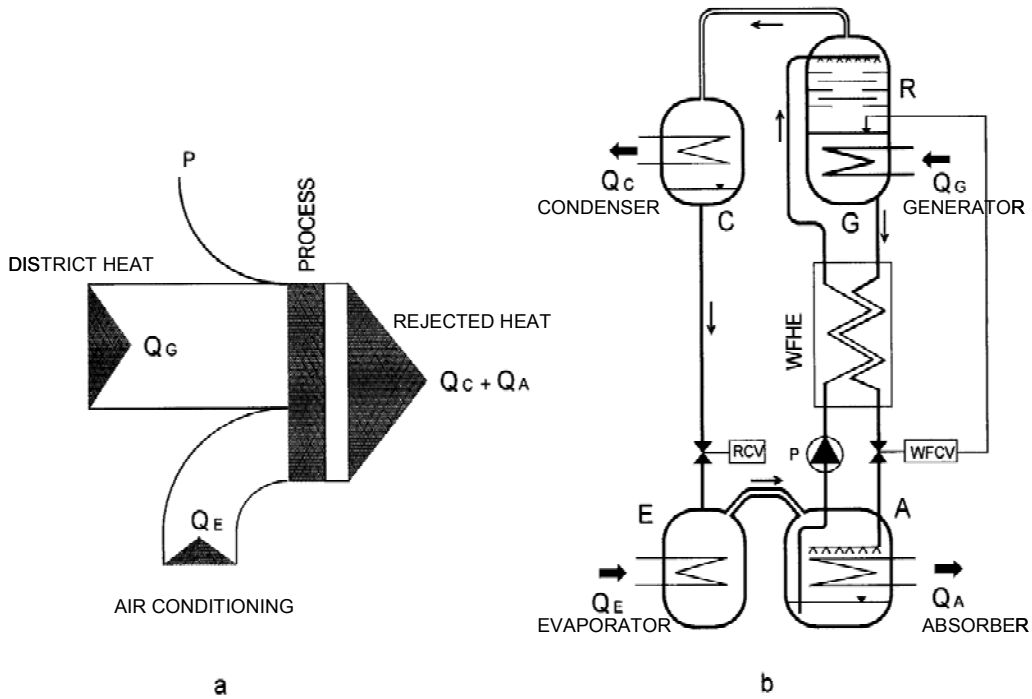

Figure 7.7: Energy flow and scheme of absorption chiller.

Model for evaluations

The PINK-ACM is operated in a detached house and therefore a suitable object for further evaluation and analysis. This air conditioning system comforts a living area in a villa via cooling-convectors controlled by a thermostat. However, the occupant preferred to control the air-conditioning manually via a switch, whenever the room is overheated and occupied by people, which is not often the case.

For the purpose of analysis, we have made a simple model where the balance temperature for cooling is 23°C, which means that a thermostat calls for cooling whenever the room temperature exceeds 23°C. How the load distribution for that could look like in a Scandinavian climate, is illustrated in Figure 7.8 for one house situated in Neidonkallio, Finland, based on data from July 2006. The DH- heat supply for one typical house in Neidonkallio for the measured climate of four weeks in July 2006 would be 188 kWh heat. The rated cooling load for a typical house is about 4 kW.

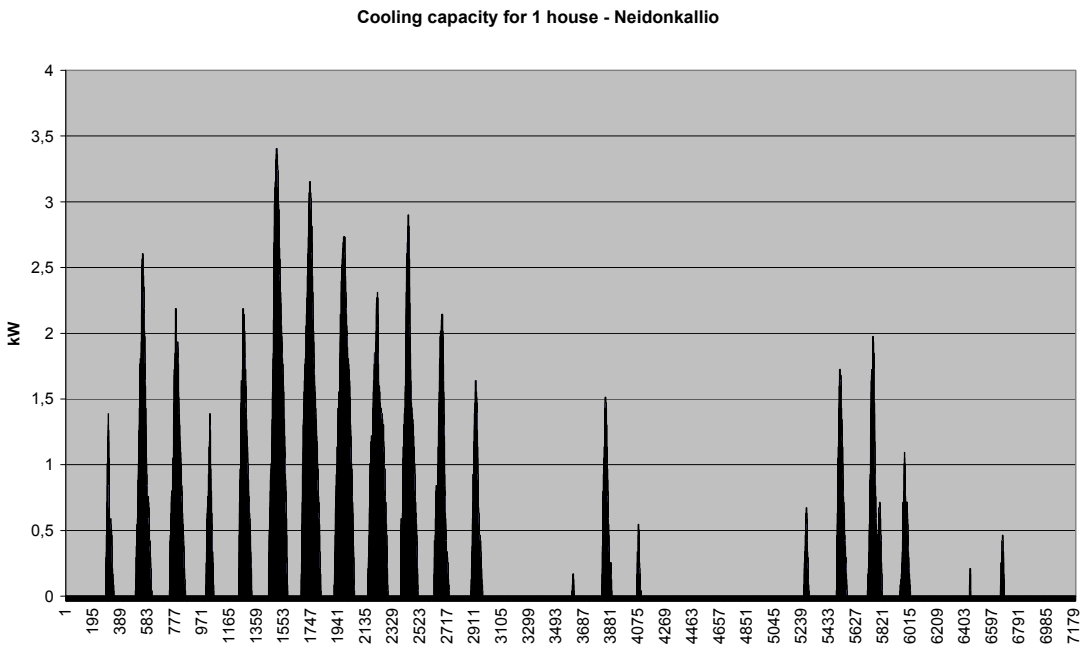

Figure 7.8: Heat load distribution in 6-minutes intervals for the heat supply to an absorption air-conditioning machine in Espoo, Finland. The values are based on the actual climate of July 2006.

7.2.3 ClimateWell

Although we believe that the market for heat-fed low capacity air-conditioning will take some time to develop, we think that it will offer an interesting option for district heating. We have the example of the electrically driven compressor-systems, which now are standard in many developed as well as developing countries. There is nothing which contradicts the hypothesis that small heat-driven systems can be developed in sizes corresponding to standard racks for household machines, i.e. 60 x 60 cm. When this is the case, the costs will have come down as well towards the amounts that people are willing to spend for a good comfort and therefore it is interesting to have alternative products. Therefore we want shortly present also another upcoming product from the absorption cooling market, i.e. ClimateWell, (see www.climatewell.com).

ClimateWell AB is a Swedish supplier of solar air-conditioning equipment for cooling requirements of residential houses. The company is developing a triple-function technology achieving a product with integrated energy storage, of heating and cooling, named ClimateWell 10. See Figure 7.9.

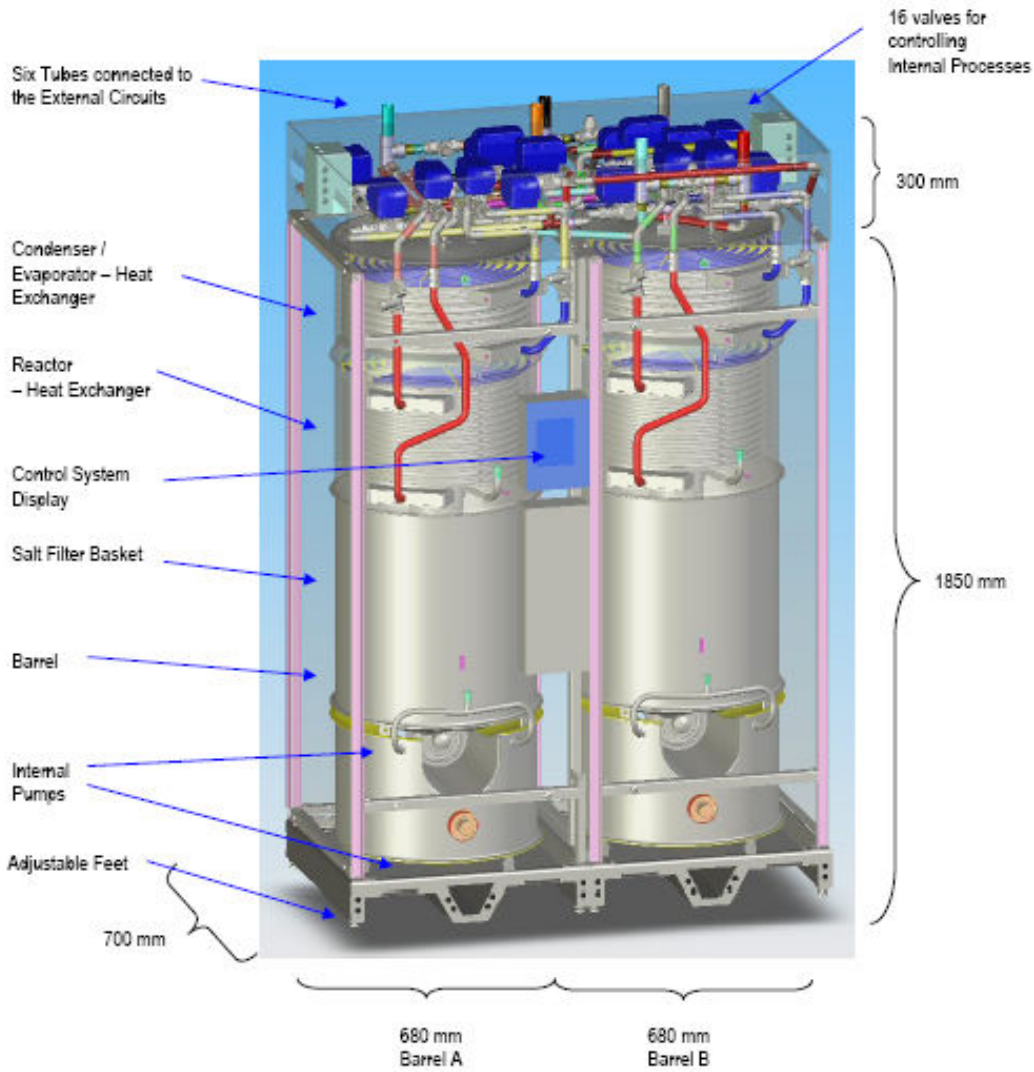

Fig 7.9: ClimateWell Absorption Machine for heating and cooling.

This modular absorption machine uses a LiCl-solution and differs from the "standard" Lithium Bromide type absorption machines in three main aspects:

- It has internal storage in each of the two accumulators. This allows the machine to store chemical energy with a very high density, drying a salt.
- It works intermittently with two parallel accumulators (Barrel A and Barrel B).
- It is designed to use relatively low temperatures and hence is suitable for summer district heating temperatures.

ClimateWell 10 has three working modes: Storing, cooling and heating. When one of the barrels is in the charging mode, the other could be in cooling mode and vice versa. Furthermore, both barrels could be working in cooling mode if both are loaded, thus doubling the capacity.

The following operational modes can be discerned:

A. CHARGING THE STORAGE

Hot liquid from the thermal source enters a heat exchanger. Normally the liquid from the thermal source needs to be at least 50ºC above the heat sink temperature for charging.

When the entering heat reaches the reactor heat exchanger, it causes the LiCl solution in the reactor to boil. When boiling, the LiCl returns to crystalline form. At the same time the water evaporates and steam is released to the condenser/evaporator where it condenses on the heat exchanger with the relatively lower temperature.

B. COOLING

The water returns from the cooling distribution system at a higher temperature than when it left the condenser / evaporator (we have cooled the building). This heat causes the water in the evaporator to boil and the steam passes down to the reactor, where it condenses, since the reactor is relatively cooler. Steam that condenses into water in the reactor will dilute the LiCl solution. The diluted LiCl solution is then pumped through the filter basket, where it mixes with the salt and regains its saturation. The saturation is needed to continuously provide a temperature difference between the condenser/evaporator and the reactor.

During discharging, the heating energy is extracted by connecting the evaporator to the heat sink and the reactor to the distribution system. Under charging, heat can also be extracted by connecting the condenser to the distribution system under charging mode.

The most important features are:

- Heating temperatures: Around 90ºC (depending of the environmental cooling temperature available, but always 50ºC more than heat sink temperature)
- Cooling capacity: 10 kW (20 kW with both barrels working in parallel).
- Electricity consumption: 170 W
- Coefficient of performance (COP): 0.68.

It is expected that the system can be commercialized within a couple of years and also enter the private market in smaller buildings or detached houses for both heating and cooling purposes. There we believe it will be a typical component in networks with low heat density distribution. The heat demand by the unit to provide cooling to a detached house will be similar to that shown in Figure 7.8.

7.2.4 Refrigerators and Freezers

In the study of Zinko and Walletun (2004) the possibility of using heat driven refrigerators and freezers was investigated. Contact has been made with a developing company that for special applications has developed refrigerators based on Water/Ammonia cycles following the early patent by Von Platen/Munter (SolarFrost, 2006). However, it turned out that using these machines as prototypes in a normal household would need further developing efforts so that the demonstration project in Gothenburg discarded these possibilities.

7.2.5 District heating connected car heaters

An interesting application are preheating of automobile engines and cabins in wintertime. This is a quite common measure in cooler climates, and normally done with electrical or fuel operated heaters. So far the preheating of the motor is concerned, this is also a recommended procedure for the reason of reducing CO_2 and other emissions caused by the cold motor. Again, using district heat instead of electricity, which is the normal way today, would be an environmentally friendly measure. An estimate for Stockholm resulted in an annual energy use of 700 kWh per car (Zinko and Walletun, 2004). In this case, electrical energy could be completely replaced by district heat and therefore an important reduction of primary energy could be achieved. For the time being however, economically reasonable solutions for doing so exist only for buses and trucks, but not for automobiles.

7.3 Other heat loads for increased comfort

In two studies conducted in Sweden, Zinko & Walletun, (2004), Zinko (2006), possibilities other than those described above for using new district heating loads were investigated. Most of these applications do not serve the fundamental needs of people but rather reflect the increased demand of comfort based on increased prosperity. In general, this is reflected by increased primary energy consumption. However, the customer is normally looking for a cost effective alternative and will very often use lower first cost electrically operated devices, especially if they are only used a few hours a year. Therefore, it is necessary that the district heating branch can come up with products that are competitive on the market. Probably, for the present, there will not be many customers who will purchase such products. But some will show interest in new district heating applications if they are available at reasonable costs and in that way the demand will be generated. In the following we will give short descriptions of such loads, some of them also tested in the Gothenburg house.

7.3.1 Greenhouses

The energy consumption of greenhouses depends on the size, the climate and the insulation standard of the greenhouse glazing. In Figure 7.10, a more fashionable solution from the Gothenburg house is shown. On only 6 m^2 ground area, a greenhouse extension to the living room has been constructed. Winter-heat is supplied by means of a district heated fed floor heating system. Double-glazed windows are protecting against large heat-losses. On sunny days in spring and autumn, the greenhouse may act even as a heat source to the living room. The calculated heat losses for this system are about 2300 kWh for the climate of Gothenburg.

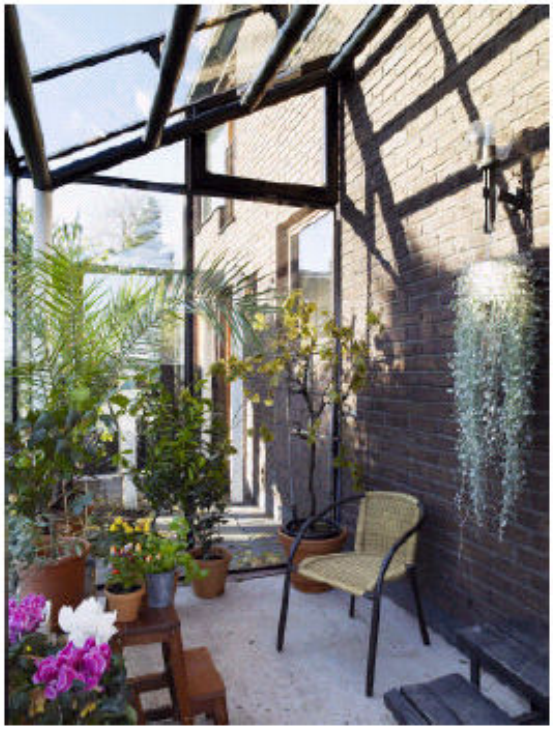

Figure 7.10: Greenhouse solution from the Gothenburg demonstration house.

7.3.2 Spa pool, swimming pool, sauna

People with preferences for modern living have normally also a desire for increased recreation. The use of Spa-tub, swimming pool and sauna is one way to find it. (Not all people, especially not the Finnish, could dream about a district heated sauna, because fire-making is part of the Sauna ceremony). The example of Figure 7.11 shows the district-heating connected Spa-tub from the Gothenburg house. It is well insulated, equipped with a water treatment system and kept at bath-level temperature most time of the year. The heat load corresponds primarily to the heat losses from the Spa and to some degree from water replenishment.

Figure 7.11: Advanced district heating fed Spa-tub of Gothenburg demonstration house.

Clearly one can have different opinions about this type of heat loads on a district heating system. The reality is that some people want to have it and in such situations it is normally better and more environmentally friendly to use district heating, eventually produced in cogeneration plants, than electrical power for heating requirements. Often sauna and/or swimming pools are wanted , so the energy use for these “wet recreations” can be equated to an energy use somewhere between 2000 and 20000 kWh/year for one family.

7.3.3 Ground heating

Snow- and ice-melting on roads and sidewalks using waste heat is quite common in some Scandinavian cities. Similar applications have been discussed for areas with detached houses, i.e. heating of staircases and walkways leading into the garden or to the main entrance of the detached house. In Northern climates, many people like the ideas of not having to shovel snow and to sand their entrance walks. It is hard to speculate in how this application will develop, depending on energy costs and other measures for reducing the greenhouse-problem. The load will add to the total energy use and therefore - maybe - people will decide to use manpower even in the future for this duty.

7.4 Energy balance for new heat loads

7.4.1 New heat loads in a detached house in Sweden

The heat loads described above are examples about how the district heating system can be used for more efficient energy use. Electrically operated appliances are very commonly used, therefore, their district heating-fed counterpart could make an important new district heating load. Other loads such as air-conditioning, greenhouse and spa tub/pool, maybe are less common, but can also make valuable contribution to the district heating load and save primary energy. (However, in order for the absorption cooling machine to save primary energy compared to an electrical compression heat pump, its COP must increase from the current value of approximately 0.6 to at least 1).

The Table 7.3 summarises some important data of new loads shown in Figure 7.12.

The Table 7.3 shows the heat load and the electrical energy used by the new machines, altogether installed in *one detached house*, assuming that they will be used over a whole year. The number of operations per year for appliances is according to the Swedish consumer association. Air-conditioning and greenhouses are operated in the climate of Stockholm. The column for *alternative use of electricity* gives the electricity used with alternative full electrical operation of all the devices (instead for district heating operation).

Table 7.3: Energy use of new heat loads

Load	Heat load per use	Electr. per use	Installed house load	Operation nb./year	Earlier use of electricity	New heat use	New use of electricity	
							process	circulation
	kWh	kWh	kW		kWh	kWh	kWh	kWh
Dish-washer	1.05	0.13	5.5	220	260	231	29	
Washing maschine	0.81	0.24	5.5	200	210	162	48	60
Tumbler	4.2	0.77	2.1	80	398	336	62	
Air-cond. COP 0.6, pumps and fans 400 W			9	Normal year	535	1425	242	100
Greenhouse				Normal year	2360	2360		100
Spa-tub				6 water changes + losses	2930	2930		870
Sum			**32.1**		**6692**	**7444**	**380**	**1130**

So far as air-conditioning is concerned, an electrical compressor air-conditioning system is considered instead for absorption cooling in this case. The last three columns show the heat and the electricity used in district heat-fed processes. The electricity used for operation of circulation pumps is presented separately. The example shows that a new heat load of 7500 kWh could replace about 5500 kWh electricity. Most important is the reduction of primary energy. This is shown in the Figure 12 for the case of coal condensing power in marginal electrical power production. The demand for primary energy in our example is reduced from 20000 kWh to 13000 kWh, i. e. by 35 %, by changing the technical subsystems from electrically to heat-driven operation.

In this example, it is assumed that all this equipment will be used in one detached house. In the system analysis from chapter 7.4.2 it is shown in the example for Neidonkallio, how the use of these new loads could look like for a whole area of detached houses connected to district heating.

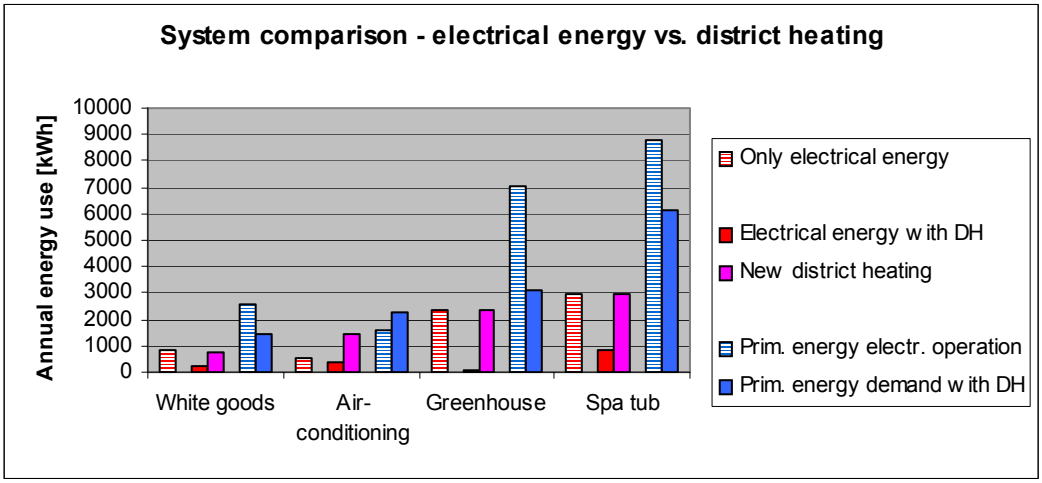

Figure 7.12: Comparison of use of final energy and primary energy for new district heating loads.

7.4.2 New heat loads in the housing area of Neidonkallio

The systems and techniques described in chapter 7.1 are operating in a villa in Gothenburg. In parallel to the installation of the equipment, also a measurement system has been installed with the objective being to evaluate the energy use and also the function of the equipment. An analysis of these measurements will be available at the end of 2008. Meanwhile we can illustrate the consequences some of these systems would have on the system of Neidonkallio.

As described in Chapter 4.1 one measurement point in Neidonkallio was the substation 1at Neidonkaari supplying heat to 17 row houses. This measurement point was equipped with a data logging system monitoring values of relevant parameters every minute which may be used for further analysis as well as simulations. Here these data are used for modelling the use of appliances and of the absorption cooling for all the row houses belonging to the substation.

In Figure 7.13, the possible use of appliances is depicted. The appliances are dish washers, washing machines and tumbler driers supposed to be installed in each of the 17 houses.

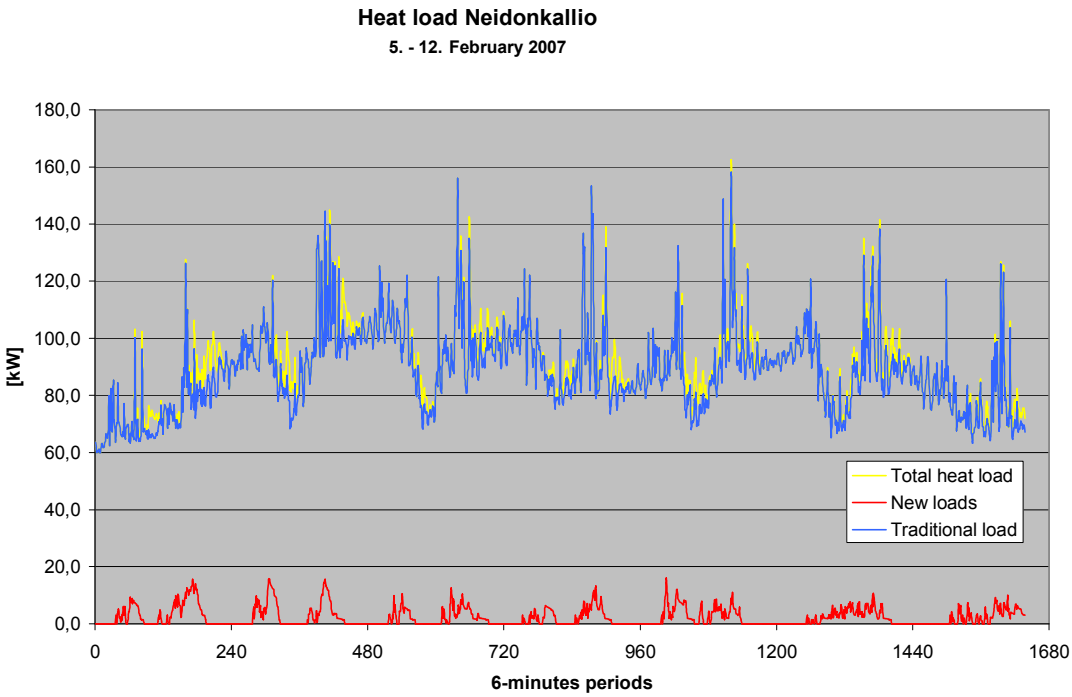

Figure 7.13: Possible use of White Goods in row houses at Neidonkaari in Neidonkallio.

The diagram in Figure 7.13 shows the measured heat load and on the bottom the new load of the appliances. In order to get a reasonable distribution of the use of the machines, it is supposed that the dishwashers are randomly used on weekdays between 6.00 and 10.00 a.m. and 14 – 22 p.m. The random distribution is shaped by a Gaussian distribution centred in the middle of the time interval. For each of the machines, the load profile according to Figure 7.5.a-c are used and the heat load (power) is appropriate as summarised in the 6-minutes intervals. On Saturday and Sunday, the operation of the machines is evenly randomly distributed between 9.00 a.m. and 21.00 p.m. The driers are assumed to start 10 minutes after the washing machine has stopped.

The frequencies for the use of the machines follow the Swedish Norm of the Swedish Customer Agency, i.e. 200 washes per year and 220 dish washes per year. The choice of the distribution profile is not based on scientific evaluation. Rather it is a method to get reasonable aggregation of the machine use.

From Figure 7.13 for February 2007 it can be seen that the total power increases due to the washes is at most 15 kW. So this power has to be added to the maximal winter load, increasing the total

load to maximum about 160 kW or 9,5 kW per house. For the area of Neidonkallio, this will not be a problem, because the piping is designed for still higher power, as explained in chapter 4.1.

In Figure 7.8, the use of an absorption chiller for air conditioning is depicted for the climate conditions of Neidonkallio. It shows the possible district heating power for the system supplying air conditioning for a typical detached house to be kept at 23ºC in July. In Figure 7.14, another example is shown, where air conditioning is delivered to all the row houses connected to the same substation Nr. 1 at Neidonkaari, together with the use of district heating driven appliances in all houses. The measurements are taken from a period in June (2 - 8 June 2007), for which measurements were available, which in difference to the July period of Figure 7.8 was not equally hot. However, there were 4 days in this week, where air conditioning would have been desirable.

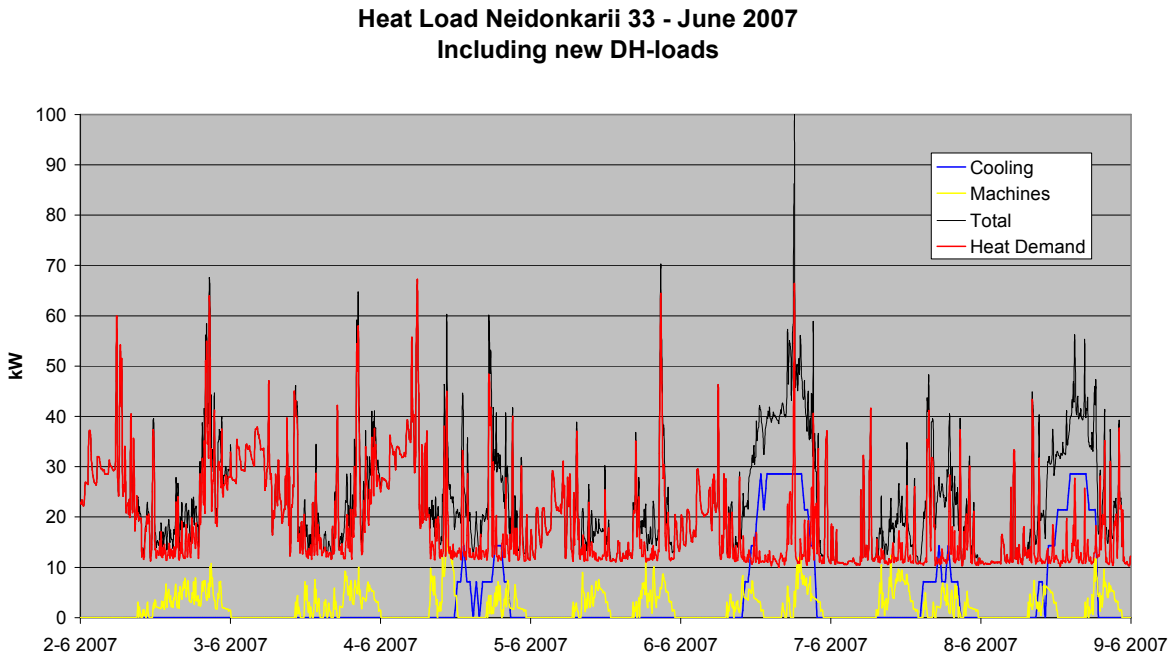

Figure 7.14: Possible use of White Goods and absorption air conditioning in June in the row houses of substation 1 at Neidonkaari.

It can be noticed, that the air conditioning system will add roughly 30 kW to the heat load (17 houses), thus increasing the total load appreciably in an area with otherwise low heat demands during summer time. It can also be seen that the heat load varies quite a lot resulting in relatively large peaks (up to 100 kW) in the late afternoon hours.

For July, the calculation shows that the cooling driven heat load would add up to 50 kW for a couple of days and 30 kW at least for ten days. However, the cooling loads are of course in Finland strongly influenced by the local climate and may vary a lot.

7.5 What customer wants

7.5.1 Energy use in some selected areas

It is well known that the use of energy in detached houses varies widely even when the occupants are living in similarly built houses. For example in an area with 100 detached houses, which was evaluated by Zinko and Bøhm, 2005, the energy use varied as indicated in Figure 7.15 for a selected sample of this area (built 1995-2000).

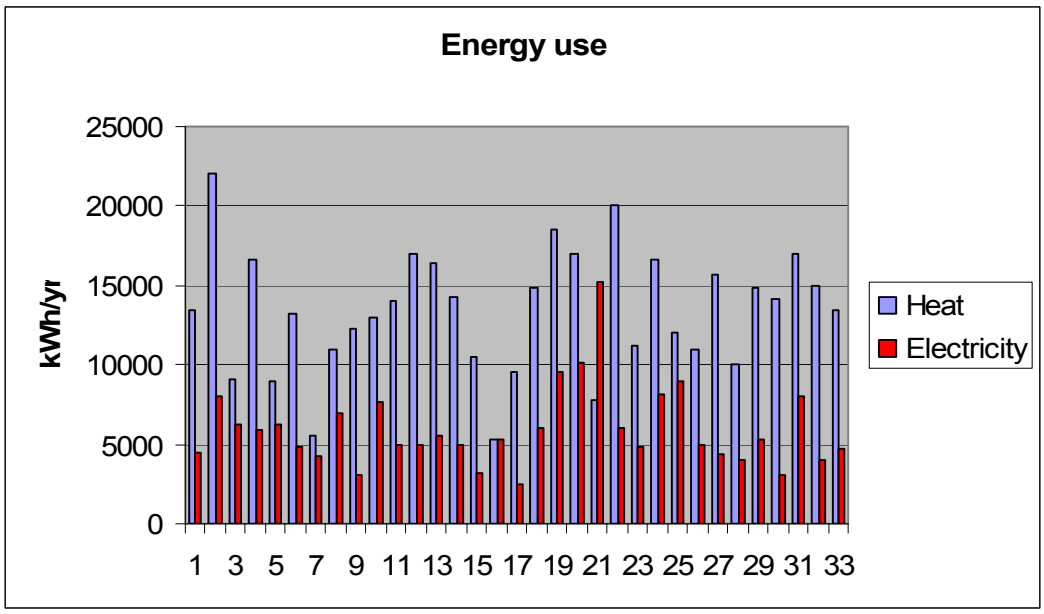

Figure 7.15: Annual Energy use for a sample of houses in Prästmarken, Växjö, Sweden.

The variation of the energy use reflects the size of the family living area to a small extent and the ways of living and the use of energy to a larger extent. For example, it turned out that on the average, 3.3 people were living in the houses, that the energy consumption was 103 kWh/m^2 per year plus 3940 kWh, and that the marginal energy use of one person was 1460 kWh, all on an annual basis. The large variation of both electricity and heat used in the houses shown in Figure 7.15 is easily explained when considering the families and the equipment used in houses, but the discrepancy it is not so easily put on a common and straight explanation.

For that reasons we carried out an interview with the inhabitants with the aim being the understanding of the life and more about the potential of novel techniques such as the equipment described in Section 7.1. Similar interviews were done in Finland in the Neidonkallio area (built 2000 -2005) and in Denmark in the evaluated system of Freuchenvej (built 1960 -1970).

The evaluation of these interviews, however, showed that for the most only qualitative conclusions can be drawn. Although we got help of the local utilities with the collection of the interviews, the response rate was about 40 % and the indications about an interest in eventual novel equipments using more district heat instead of electricity was very rarely answered; probably people were fearing an intense marketing of new equipment as a consequence of their responses (it was explicitly stated in the interview form that such would not be the case).

What we have seen in the interviews is that practically all homes have washing machines and dish washers, and half of them have also tumble driers. Furthermore, about half of the detached houses in Sweden and Finland are equipped with additional fireplaces (indoor). People in the Finnish area have to a large extent compressor driven air conditioning (probably in form of an electrical outdoor air heat pump) and of course a Finnish Sauna. Electrical motor (car) heaters are much more common in Finland than in Sweden. As to Denmark, the answers are too sparse in order to allow general conclusions.

The answers also reflect to some extent the electricity use of respective countries. Finland and Sweden have long traditions of using electricity for heating purposes and traditionally have a more generous attitude towards using electricity. In Denmark, electricity is generated largely with fossil fuels and hence more expensive than it is in the other Northern countries and therefore the use of electricity is more restricted. Swimming pools and Spa tubs are not very common in general and nor is the heating of ground and greenhouses.

7.5.2 Novel equipment for district heating

From the answers in the three different areas, we cannot conclude that people indicated that they are interested in changing their energy use habits. From the experience in Gothenburg, however, we can conclude that people are interested in new possibilities, if they are properly explained and operating safely and reliably. Furthermore, of course there should be an incitement in order to leave the tried and true behind when testing something new. People have acquired Internet IT technology because the added value is obvious, although it is associated with appreciable additional costs. For the sake of using district heat instead of electricity, it is necessary to market the possible advantages: *Reduction of greenhouse emissions, increased use of cogeneration, increased sustainability of energy use, a. o.* For some people, these arguments will be good enough, but others will want to see the economic trade-off, which is not so justified at present, mostly due to the fact, that modern appliances are very energy-effective already. The change from electricity to heat is not so easily paid for by the possible energy savings. In addition to the investment costs, we have the costs for the additional house installations. Hence it should be in the interest of the utilities to start the marketing of these novel technologies and their use.

7.5.3 An initiative for marketing activities

As it described in the previous chapters, we are standing today on the edge of a new possibility of using district heating equipment for a series of new applications. The most widely used of these are appliances. Most people in district heating countries are using dish washers and washing machines in their homes and about half of them even use tumble driers. And this is not only the case in detached houses but also in the generally speaking much larger district heating segment of multifamily houses.

Therefore, we propose that district heating utilities take the initiative for marketing these new possibilities. However, this cannot be done without having reliable products available.

Appliance manufacturers, for example, are reluctant to enter this market for many reasons: District heating, they say, is covering only a market segment around 8 % in Europe. However, this is not the only market. The Swedish project evolved from cooperation with solar heating applications, and hence the fast growing solar energy market together with the biomass market represents also a large and growing market. District heating is reaching in Europe about 100 million people or about 30 million households (Werner, 2006), and other renewable energies at least equally as much. That means that the potential market should be large enough to offer new appliance products.

The air conditioning business for smaller applications, on the other hand, which for the moment is heavily bound to electricity, can also constitute a very fast growing market for district heating utilities, similar to what is the case for large cooling applications.

We have learned from discussions with the equipment industries that a development can be instigated by just describing the products and the market. The technology is available, so far as appliances and absorption systems are concerned.

Hence we propose the following measures be taken by utilities, maybe on a European level or within IEA:

1) Approach the appliance and AC industries and show them the technical possibilities for using heat driven equipment.
2) Define the markets for each application.
3) Approach other branches (solar energy and biomass, f. i.) to join the activities.
4) Develop installation schemes for both detached houses and multifamily buildings.

5) Inform the market about the products and about the possible environmental profits.

6) Initiate campaigns inviting customers to participate in installations with economically attractive costs.

7) Offer the producers of equipment safe contingents which allow large production quantities and low product costs.

8) Offer to users maintenance and operation support.

9) Develop some kind of green certification for the use of such machines.

10) Form an evaluation programme in order to continuously follow up the activities.

The prospects are good to increase the use of new types of novel heat applications and thus leave electricity to the higher uses of it.

8 Improved system solutions

Summary:

This chapter describes results of system analyses performed at first hand to illustrate eventual cost saving that can be received by careful system design. In this case the main changes are the use of twin pipes instead of single pipe systems, smaller pipe dimensions, eventually with booster pump, varying insulation thickness, new routing (house to house) and the use of hot water tanks instead of direct connected hot water preparation. Two systems, one in Finland (Neidonkallio) and one in Denmark (Nykøbing/Falster) are investigated. It is shown, that both heat losses and investment costs can be decreased with suitable system designs.

8.1 Neidonkallio, Finland

The network simulation model presented in Chapter 4.1 is used to simulate and compare different type of net layouts and piping solutions. The purpose is to find the most cost economic solution for local networks in areas of sparse district heating.

The interaction between supply and return pipes is taken into account when calculating the heat losses. The equations used are (see Appendix 1 for more details):

$$Q_{feed} = U_1\left(T_{feed} - T_{ground}\right) - U_2\left(T_{return} - T_{ground}\right)$$

and

$$Q_{return} = U_1\left(T_{return} - T_{ground}\right) - U_2\left(T_{feed} - T_{ground}\right).$$

By means of the model, a total of seven different cases were simulated. These were single pipe networks with three different insulation thicknesses as defined by series 3, 2 and 1 insulation standard, a normal twin pipe network, reduced supply temperature scenario, reduced pipe diameter scenario and a house-to-house network system (Figure 8.1.1). The existing network of Neidonkallio is a single pipe network with insulation according to standard series 3.

Excluding the last two simulation cases, the pipe sizes and lengths are identical to existing networks. In the reduced supply temperature scenario, the supply temperature at the entry point of the network is lowered by 10ºC. In the reduced pipe diameter scenario, smaller pipe sizes were redefined using a thumb rule of an acceptable pressure drop of 0.5 – 1.5 bar/km in all pipes. House-to-house network is a special setup where customers are basically connected straight to each other, minimizing the length of the service pipes to about 2 m per house. This causes a reduction of the total length of the network from originally 2.5 km to 1.6 km. In the reduced supply temperature scenario, reduced pipe diameter scenario and house-to-house network, single pipes with insulation according to standard series 3 were used.

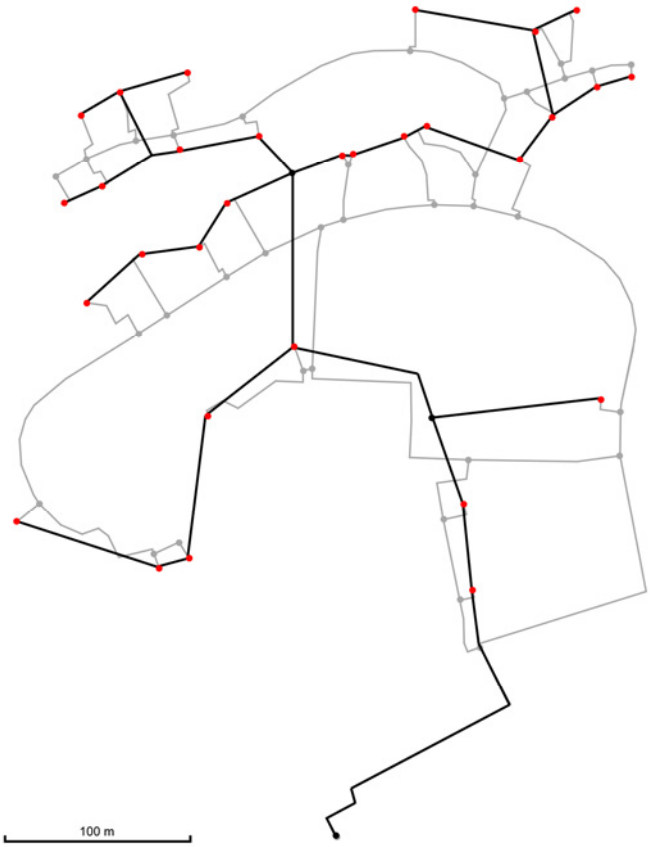

Figure 8.1.1: The house-to-house network, without the short service pipes (2 m). Original network for comparison as background

Figure 8.1.2 shows the different pipe size distributions used in simulation cases.

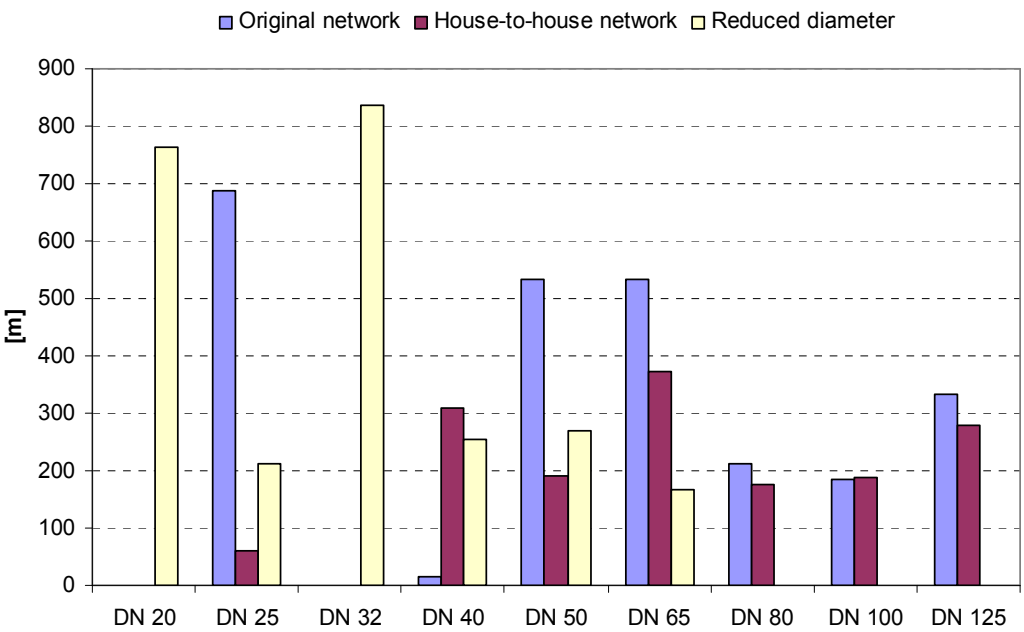

Figure 8.1.2: Pipe size distribution in three different simulation cases. The total length is 2.5 km in original and reduced diameter network, 1.6 km in house-to-house network.

Figure 8.1.3 shows how heat demand and heat loss relate to each other. As can be seen, heat loss appears to remain relatively unchanged even at varying heat demand. The pumping power is relatively small and follows the heat demand closely.

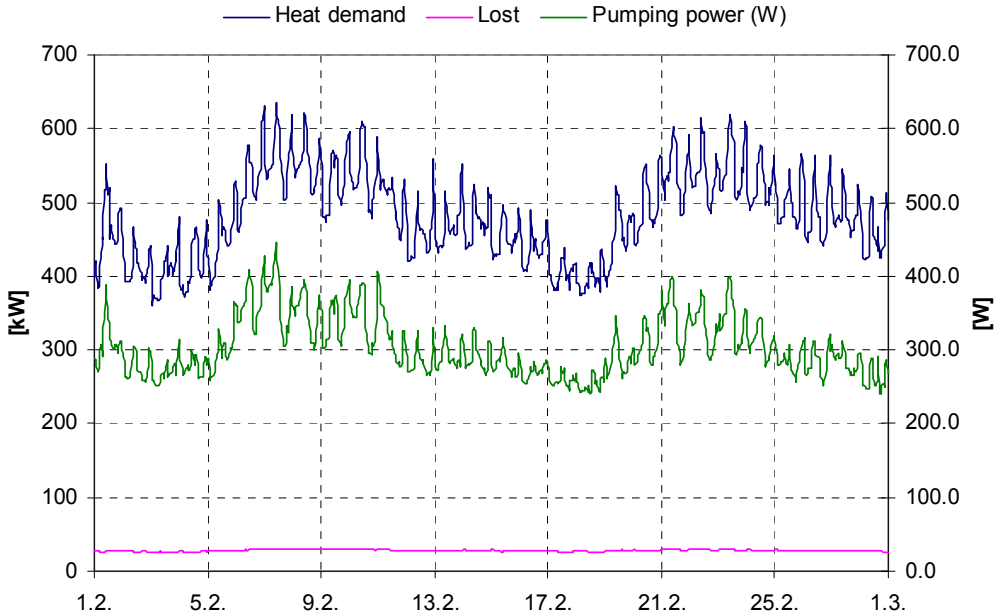

Figure 8.1.3: Heat demand, simulated heat dissipation and pumping power in original single pipe network with series 3 insulation.

Figure 8.1.4 below shows heat loss and pumping power in the simulated cases. It can be seen that the use of twin pipes, reasonably sized pipes and minimized network length as well as lowering the supply temperature have an impact on heat loss. These results are not unambiguous, as some of the solutions are not as good as they seem. When dimensioning the pipes, the future development of the area must be taken into account. At the moment, Neidonkallio area is still growing and the pipe sizes in the reduced diameter scenario might not be suitable in the future. Minimizing network length is an obvious solution to cut heat losses, but house-to-house network setup might be too inconvenient in practice because of the required permits and the maintenance of pipe systems running through private premises. Lower supply temperature means lower heat losses and should be set as low as possible to still meet heating demands. Twin pipes seem a good solution in terms of heat dissipation in small areas, where no large diameter pipes are required as maximum available size for twin pipe is currently DN 125. As service pipes, twin pipes are very suitable for any network.

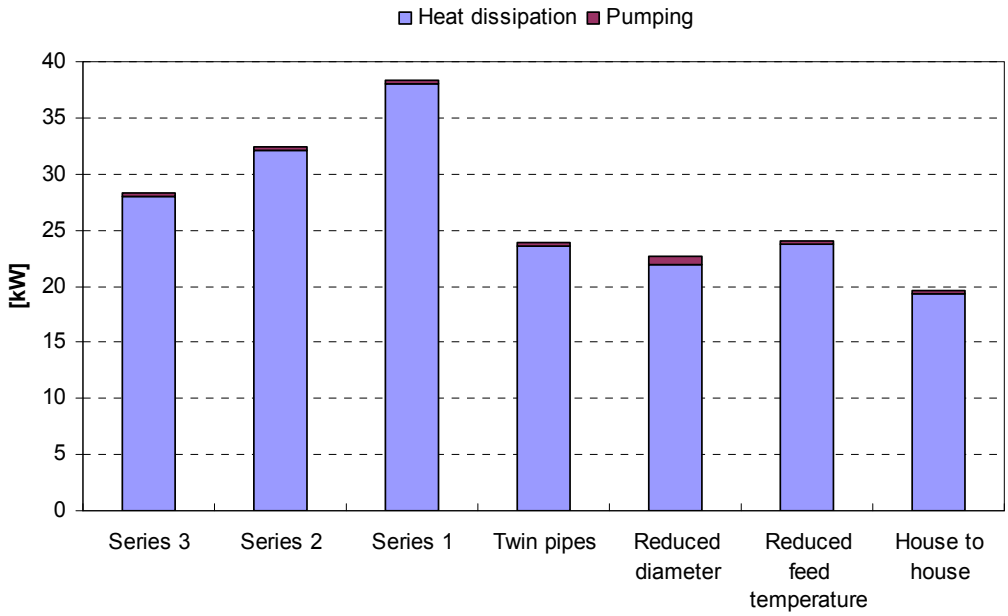

Figure 8.1.4: Average heat loss and pumping power in different types of DH heating net solutions according to simulations for Neidonkallio (February 2007).

The pumping power calculated in Figure 8.1.4 is a hypothetical value. It only takes into account the flow and pressure differences in Neidonkallio area calculated by the model. In reality, the actual pumps would be located at heating plants or pump station elsewhere in the network. Also, when calculating the absolute pressures, the model assumes that the lowest pressure difference of a customer substation in the network happens to be in the Neidonkallio area. The pump efficiency used was 50 % and assumed to be constant.

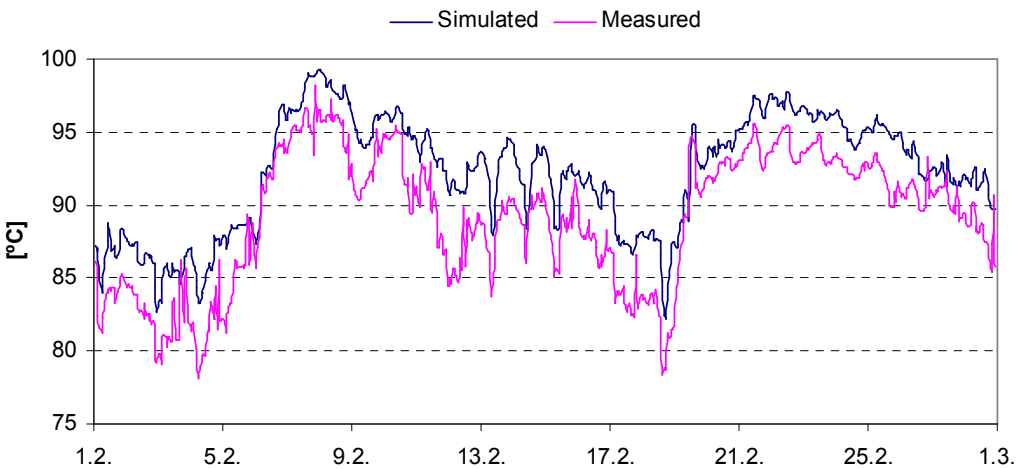

Figure 8.1.5: Simulated and measured supply temperatures in a specific nod in the original single pipe network with series 3 insulation. Average deviation is 3.4 %.

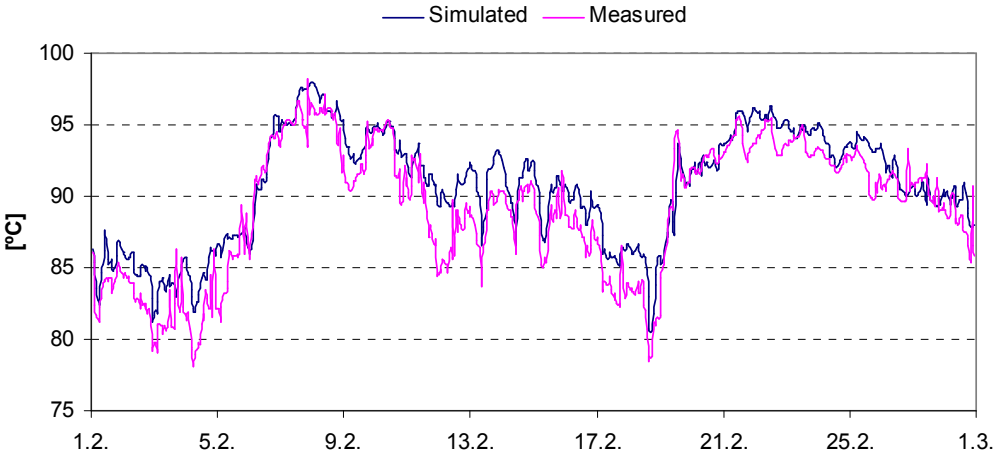

Figure 8.1.6: Simulated and measured supply temperatures in a specific nod in original single pipe network with series 1 insulation. Average deviation is 1.7 %.

Figures 8.1.5 and 8.1.6 above compare measured and simulated supply temperatures in a specific point of the network in simulations with series 3 and 1 insulation. The location of the comparison point is the blue dot indicated in Figure 4.1.9. It is known that Neidonkallio network consists of pipes with series 3 insulation. Comparison Figure 8.1.5 and 8.1.6 makes evident that the network model underestimates somewhat the heat losses, giving slightly higher supply temperatures as a result. The simulation case using pipes with series 1 insulation produces results closer to the measurements.

8.2 Peter Freuchenvej, Nykøbing Falster, Denmark

8.2.1 Introduction to system analysis

As previously described in Section 4.2 the network at Peter Freuchenvej was renovated in 2006. In this section we compare the new twin pipe network with the previous system made of single preinsulated pipes. We also investigate if further improvements could have been obtained by better designs.

To this end we redesign the network under the assumption that all buildings and installations are identical. Thus it is assumed that all buildings have a hot water tank, or a hot water heat exchanger. Annual heat demands for hot water of 2300 kWh and for space heating of 17 700 kWh are assumed.

The design of the network is made by use of the models described in Section 4.2.1 with regards to cooling of the DH water and to aggregation. It will further be assumed that a pressure difference of 100 kPa is available at the entrance to Peter Freuchenvej.

The energy for circulating the water is treated approximately, assuming that a pump is located at the entrance to the area and ignoring the other pumps in the Nykøbing/Falster network. It is further assumed that 60 % of the pumping energy is converted to heat in the pipes.

The different systems are compared by calculating the Net Present Value of operational costs and investments. Only those costs that differ from system to system are considered, i.e. investments in the space heating system are not taken in to account.

A net present value factor of 11.47 is used, corresponding to interest rate 6 % and time horizon 20 years. The prices shown in Table 8.2.1 are applied. The prices reflect the economic viewpoints of the customer and the producer. The customer has to pay energy prices including taxes and other fees, the producer can calculate with net prices.

Table 8.2.1: Operational costs from customer and producer viewpoint.

	CUSTOMER	PRODUCER
HEAT	55 EUR/MWh	33 EUR/MWh
ELECTRICITY	0.138 EUR/kWh	0.070 EUR/kWh

8.2.2 System comparison

Table 8.2.2 shows the investigated DH systems. The table shows the length of the different pipe dimensions, and the network temperature difference. The temperature difference depends on the operational strategy, i.e. constant supply temperature of 80°C or variable supply temperature 60-80°C, and on the cooling of the DH water by the house unit (HWT or HWHEX). The table further shows the heat loss coefficients and the annual heat loss as well as the pumping demand. Finally, the table shows the heat loss from the hot water heaters (HWT or HWHEX) and electricity used by a booster pump at the customer substation. For reasons of simplicity we assume that 50 % of the heat loss from the units is utilised for space heating.

Table 8.2.2: Investigated system (Nykøbing/Falster).

NETWORK	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
DIMENSIONS/ Pipe Lengths, m	**Single 2005**	**Twin 2006**	**Twin HWT**	**Single HWT**	**Twin HWHEX**	**Twin HWHEX Boosters**
Ø16 PEX	0	276.3	276.3	276.3	4.5	307.8
Ø20 PEX	0	31.5	31.5	31.5	177.7	0
Ø22 PEX	96.5	0	0	0	0	0
Ø26 PEX	0	0	0	0	125.6	0
Ø28 PEX	11.0	0	0	0	0	0
Ø27 Steel	0	8.4	75.2	75.2	0.2	0.2
Ø34 Steel	200.3	55.1	56.2	56.2	116.2	116.2
Ø42 Steel	29.5	15.4	45.2	45.2	60.2	60.2
Ø48 Steel	0	71.0	90.1	90.1	90.1	90.1
Ø60 Steel	12.5	116.8	0	0	0	0
Ø76 Steel	118.7	0	0	0	0	0
Ø89 Steel	90.3	0	0	0	0	0
TOTAL	559	575	575	575	575	575
NETWORK TEMP: DIFF						
ΔT, K	51 [80/40/9] or 39.5	51 [80/40/9] or 39.5	39.5	39.5	35.0	35.0
HEAT LOSS						
2(U1-U2), W/K	216.22	109.99	103.51	148.47	113.50	104.17
Annual, MWh	97 or 74.8	49.1 or 38.0	35.80	51.35	34.82	31.95
Efficiency	0.77 or 0.81	0.87 or 0.89	0.90	0.86	0.90	0.91
PUMPING	Const. / var.	Shunt pump	Var.	Var.	Var.	Var.
Max. flow, kg/s	0.86		0.86	0.86	0.96	0.96
Max. Hours	335 or 940		940	940	940	940
Annual, kWh	41 or 115	(1500)	115	115	129	129
HOUSE UNIT						
Heat Loss, kWh	(1315)	(1315)	1315	1315	439	439
Booster, kWh	0	0	0	0	0	18

The following cases are analysed:

Case 1: Single Pipes 2005, hot water tanks, direct space heating system. Variable supply temperature. Actual dimensions and lengths.

Case 2: Twin Pipes 2006, hot water tanks, direct space heating system. Variable supply temperature. Actual dimensions and lengths.

For both case 1 and 2, the real system consists of a mixture of HWT and HWHEX.

Case 3: Twin Pipes, hot water tanks, direct space heating system.

Case 4: Single Pipes, hot water tanks, direct space heating system.

Case 5: Twin Pipes, hot water heat exchangers, direct space heating system.

Case 6: Twin Pipes, hot water heat exchangers, booster pumps, direct space heating system. In this case, smaller dimensions for service pipes are used by installing a booster pump in each service pipe.

Indirectly connected space heating systems will not be considered here as these systems increase the investments costs by an extra heat exchanger and they result in a higher return temperature from the space heating system.

Results

Heat losses and net present values are shown in Figures 8.2.1 - 8.2.3. Figure 8.2.1 shows that it is possible to reduce the heat losses considerably, both by good design and by reducing the supply temperature as a function of outdoor temperature.

The main results from these NPV calculations are summarised in Table 8.2.3.

Table 8.2.3: Annual operational costs and NPV in EUR per house for 6 alternative system solutions for Peter Freuchenvej, Nykøbing/Falster.

EUR per house	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
Network investment	**7546**	**5588**	**5352**	**6338**	**5553**	**5384**
CUSTOMER viewpoint						
Annual operational costs	294	170	160	213	132	126
NPV Total	24 736	21 360	21 004	22 604	20 489	20 379
PRODUCER viewpoint						
Annual operational costs	176	102	96	128	79	75
NPV Total	18 342	15 533	15 226	16 580	14 836	14 753

As it can be seen in Table 8.2.3, the twin network installed in 2006 (case 2) reduces investments and operational costs compared with a new single pipe network installed with the previous dimensions (2005). The difference in NPV is 3376 per house.

Cases 3 and 4 are redesigned systems based with hot water tanks. It can be seen that the use of pairs of single pipes increases the NPV.

Cases 5 and 6 are redesigned systems based on hot water heat exchangers. In case 6, a booster pump is used to reduce the dimension of the service line. We found that these systems reduce the

NPV by 870-980 EUR per house compared with the actual system (case 2). These figures are from the customer viewpoint. However, the conclusions are the same from the producer viewpoint.

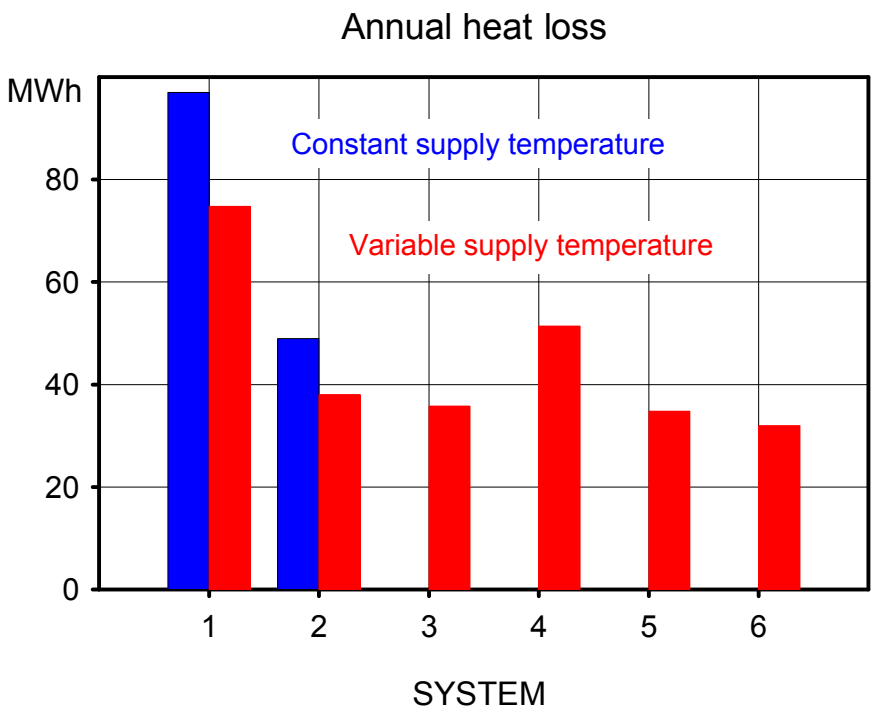

Figure 8.2.1: Annual heat losses from the 6 DH systems, shown in case of constant and variable supply temperature.

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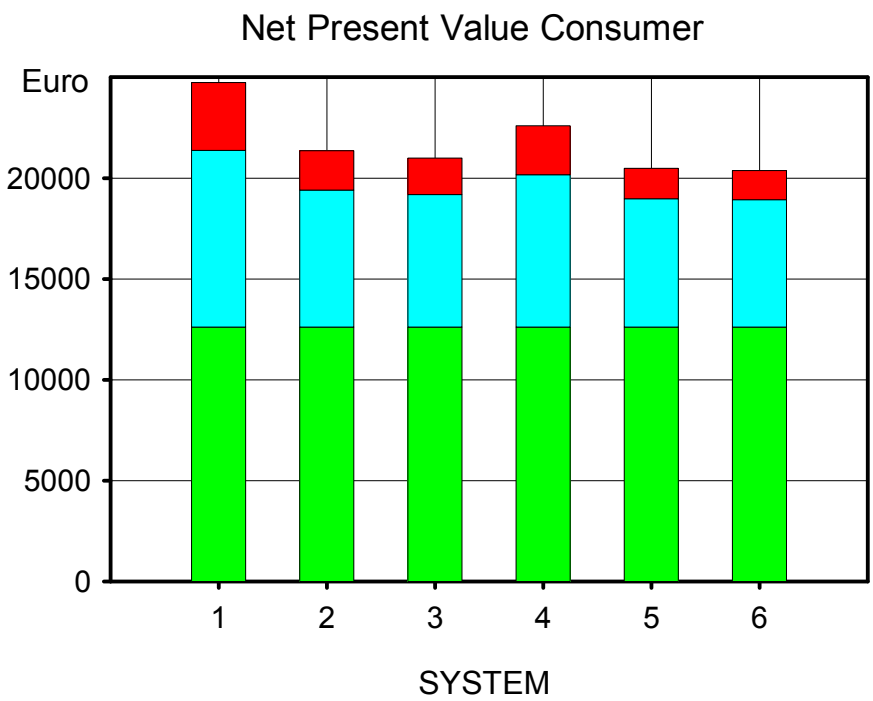

Figure 8.2.2: NPV of the 6 DH systems seen from the customer viewpoint. Green: Heating costs; Light blue: Investments; Red: Operation costs.

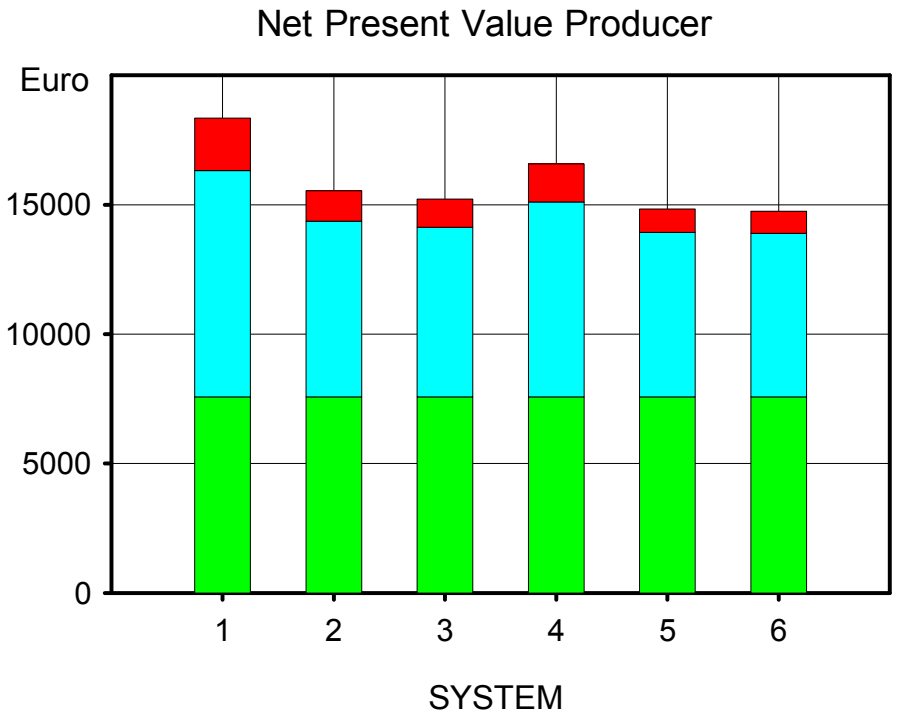

Figure 8.2.3: NPV of the 6 DH systems seen from the producer viewpoint. Green: Heating costs; Light blue: Investments; Red: Operation costs.

9 Future connection of areas with low heat demand density

Summary:

This chapter summarises the most important measures for achieving cost-effective connection of buildings in areas with low heat demand density, applicable especially on small heat loads such as detached houses. The chapter presents a checklist of items that are important for cost reduction when planning a district heating network, whether it is for an area with existing detached houses or for a new exploration area. To minimise pipe dimensions and groundwork is important in every case. In addition, different types of substations are described, although it is difficult to give generic recommendations because of varying local conditions. Finally, the importance of reaching a high degree of connection for local district heating networks is underlined.

9.1 Introduction

The ultimate goal of the work in this report is to stimulate utilities and other energy providers, such as local house owner groups, to consider areas with low heat density as potential market places for new district heating, rather than dismissing them due to potentially high investment and operating costs. Over recent decades, district heating techniques have been developed to the extent that it is possible to deliver heat not only to areas containing rows of houses and tightly built detached houses, but also to traditionally spaced villa areas, as the example from Finland shows. In energy terms, it is fully possible that district heating can be delivered to areas with an annual load as low as 10 kWh/m^2, whereas (maybe) 30 kWh/m^2 was conventionally considered as being the lower limit for district heating supply just a couple of decades ago. Some new approaches to this issue are described in chapters 5, 6 and 7.

The reason for reaching lower heat densities nowadays is to be seen in the fact that energy prices increased in recent decades and that technological improvements led to a reduction of both investment and operational costs. An additional point is that the house owners themselves started to work with energy efficiency programmes, for the sole reason, that up to a certain degree, the saved kWh is cheaper than the purchased one. Therefore, a general approach for district heating utilities in a saturated market to stay in profit is to connect new customers to the existing stem network, selling about the same amount of energy from year to year to a larger number of customers. For example, the Swedish DH utilities delivered in the last years about 47 TWh heat to the ensemble of piping networks, which increased by about 3 % each year in length. Most of this net expansion is due to heat delivery to detached houses, as can be seen in Figure 9.1.

Indeed it is the case in many countries with a long tradition of district heating, that the only expanding market segment is detached houses, whereas heat delivery to the traditional market segments is decreasing. However, it should be mentioned that in Denmark about 1million detached houses (i.e. 63 % of all detached houses) are connected to district heating, whereas the connection ratio of detached houses in Sweden is around 13 %.

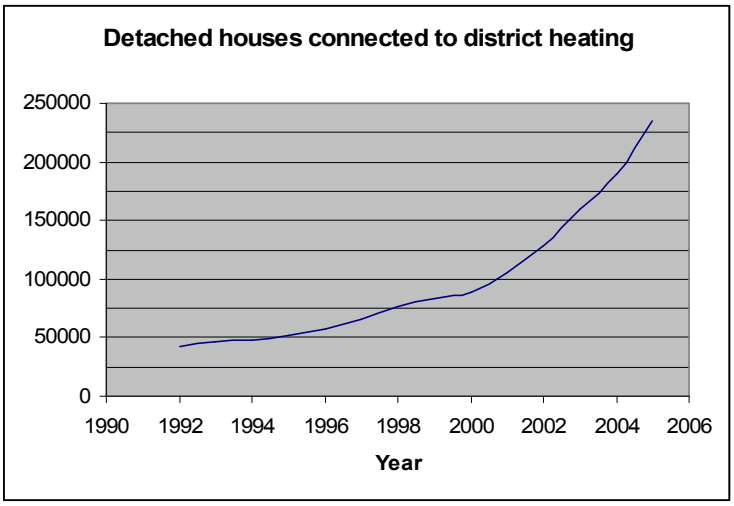

Figure 9.1: Total number of detached houses connected to district heating in Sweden, 1990 -2006.

9.2 District heating pipe system for detached houses

Starting from the traditional way of constructing district heating, it can be asked: What are the most important measures for making installation in detached houses profitable? From Figures 6.6 and 6.8 simple conclusions can be drawn: *Reduced installation costs and reduced heat losses*. Both can be achieved at the same time by using smaller dimension for pipes. Furthermore, one other important way of reducing heat losses (besides lower operating temperatures) is the use of twin pipes or even triple pipes (see chapter 5).

From a study made in the Swedish sparse district heating programme (Sandberg, 2003), the following relative distribution of costs was found for connection of detached houses to district heating:

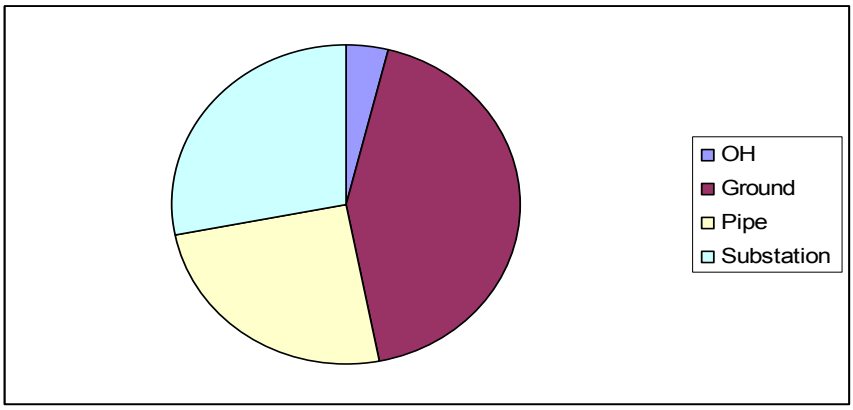

Figure 9.2. Project costs specified for management and overhead, groundwork, duct work and house substation.

From Figure 9.2 it can be seen that the groundwork corresponds roughly to half of the total installation costs. That means that a lot can be saved by decreasing both the length of the trench and the area of the trench section. In Figure 9.3, a series of measures is depicted, illustrating how the trench section can be reduced. In the example shown, the reduction of the areas is more than 50 %.

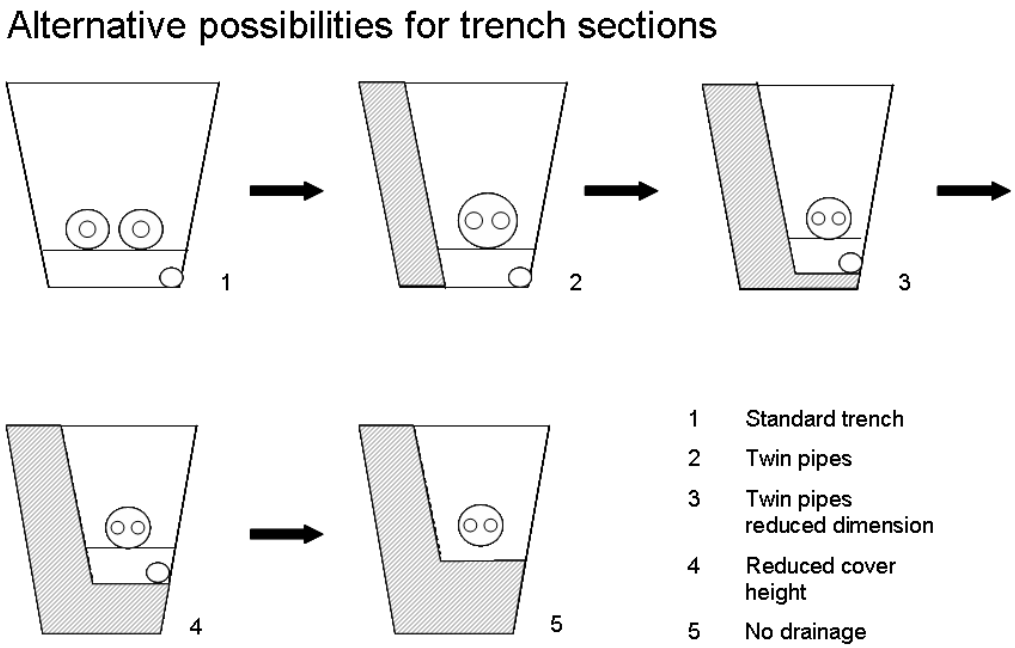

Figure 9.3: Reduction of trench section area leads to lower pipe system costs (shadowed are = saved ground excavation).

It should be pointed out that the type of reduction must be chosen carefully, so that the safe function of the network is not spoiled. Hence, reduction of pipe dimensions must be checked for available pressure difference or the possibility of adding a booster pump. The omission of drainage pipes must be reliable, but can be chosen for dry ground environments. According to the cost calculation shown in Chapter 5, the cost reduction between Type 1 and Type 5 could be around 70 US$/m, where the use of Twin pipe could give 30 US$/m and the use of smaller and less deep trenches would give around 40 US$/m. Additional reduction could be achieved for the smaller asphalt layer. Further cost reduction is due to the omitted drainage pipe. Depending on the local conditions, the reduction of dimensions may sometimes only be applicable on the service pipe system.

When planning the connection of a new area with detached houses (or other customers involving low heat line density), the checklist presented below should be worked through.

TYPE OF SYSTEM

Choice of system type:

- *Primarily connected* to district heating – useful when only a proportion of customers can be connected from the beginning, but it can be expected that more customers will join in the future.
- *Secondary connection* by means of main substation – suitable when the group of costumers is defined and no further connection expected. Can normally be designed with lower pressure and lower temperature. Alternatively, the secondary system can be connected directly via a thermal or hydraulic shunt.

PIPE SYSTEM

Reduction of pipe dimensions:

- Reduce the pipe dimension as much as possible *without* keeping capacity reserves. Learn to use the full capacity of the network.
- Eventually a booster pump will be needed.
- Eventually a hot water store could bring advantages.
- Make sure that the piping uses the best available and lasting insulation.
- Investigate if 3-pipe or 4-pipe systems could reduce costs.

Reduction of trench area:

- If twin pipes are not initially proposed, investigate the reasons why not?
- Check if heavy traffic is expected. When the pipe is not placed in the road, make the trench as shallow as reasonably possible.
- Check if drainage is needed, otherwise leave it out.

Reduction of trench length:

- Check whether it would be possible to have a house-to-house routing? A discussion with the house owners might clear this issue.
- In some cases it could be possible to install the pipe systems in the crawl space beneath the floor (often disliked by district heating companies).

Choice of digging method:

- Choose the routing so that the majority of the trench is in easily excavated ground, avoiding asphalt areas.
- Minimize open roads and roads which must be asphalted.

Pipe Installation:

- Use flexible pipes with suitable lengths and use press-fittings for joining pipes. Flexible pipes can be in copper, steel or PEX (Figure 9.4).
- Do joining work above ground level.
- Plan pipe installations without the need for preheating.
- For crossing roads remote drilling methods could result in lower costs (depending on the local situation).

– In gardens and park areas use chain-diggers or other devices working with small trench widths (Pohl, Klingman, 2006).

Figure 9.4: Flexible pipes can be in copper, steel or PEX (Sandberg, 2003).

9.3 Customer substations

Different methods can be used, but not all are accepted by the local utilities. Follow the recommendation of the local utility: The following methods for house connections are often used, Figure 9.5:

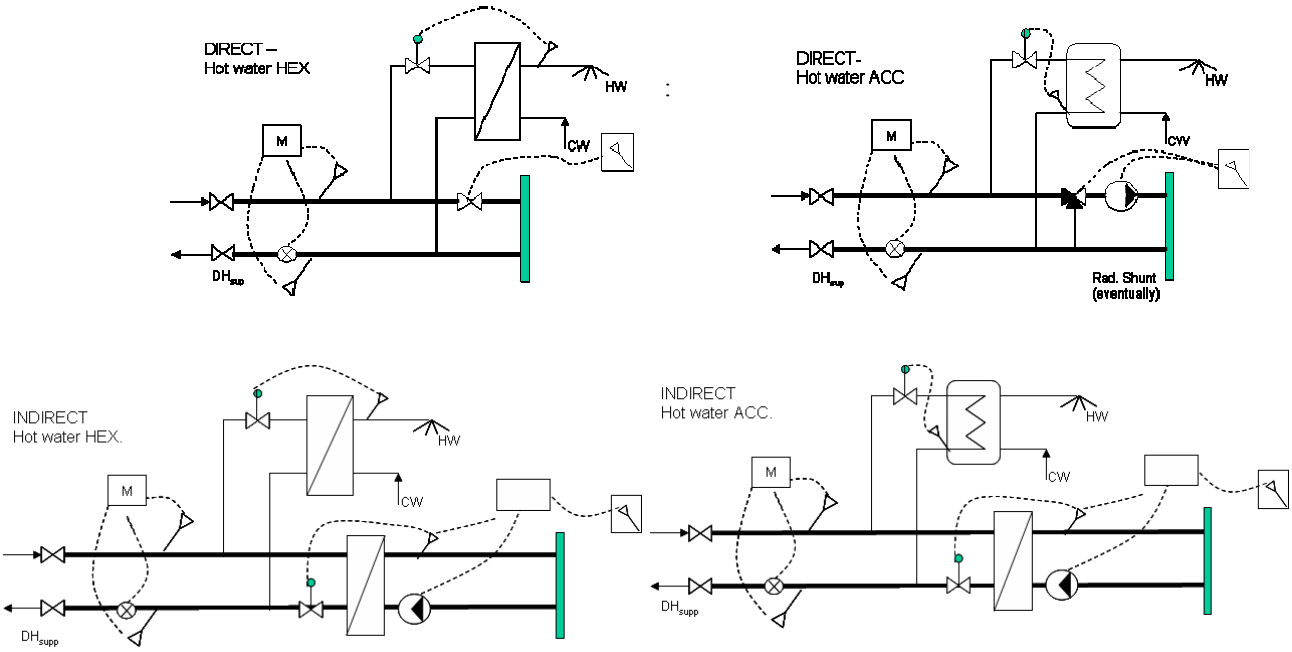

Figure 9.5: Alternative connections of detached houses to the district heating network.

- Direct connection of radiators/floor heating systems and hot water accumulator
- Direct connection of radiators and hot water preparation in direct flow heat exchanger
- Indirect connection via two parallel heat exchangers (hot water, radiator heat)
- Indirect connection of radiators and hot water accumulator.

In systems with hot water accumulators, smaller service pipe dimensions can be used than in directly connected heat exchangers. However, the loading sequence has to be controlled carefully in order to keep return temperatures low. Direct systems are often used in small district heating networks or in secondary networks. This connection is very common in Denmark. In Sweden and Finland, the Standard connection is two parallel connected heat exchangers, one for the radiator system and the other one for hot-water preparation. All types of substations include a number of components not shown in these schemes. For example very often the directly connected substation must be equipped with pressure difference controllers, something which can reduce the apparent cost advantage of direct connection.

Modern customer substations without accumulators are normally very compact installations, often prefabricated, which can also be easily installed outdoors in small service boxes or huts, and by such a way facilitate access and maintenance and saving indoor space (Figure 9.6).

The cost of substations are therefore very difficult to generalize, certain types of substation can be locally favoured and installed in large numbers, which can result in low costs even for a substation including many components. Also the costs of substations including a hot water accumulator instead of a heat exchanger can differ quite a lot from place to place, depending on size and quality, and therefore it is generally wise to follow the recommendations of the local utilities, which very often have cost-negotiated solutions to offer.

Figure 9.6: Prefabricated substation and possible outdoor installation.

9.4 The importance of high degree of connection

Aside from suitable planning and design of the technical solutions of district heating networks, the customer penetration, i.e. the degree of customer utilisation is very important. The cost of a local district heating distribution system consists of the following three main parts: Cost of *distribution network*, cost of *heat losses and* cost of the *service pipes*. The specific costs per customer for network and heat losses are dependent on the utilisation of the system, i.e. the number of customers connected to it. The costs for the substation and service pipes, in contrast, are supposed to be constant per customer.

The total cost for a new area to be connected is dependent on how many customers can be expected to connect from the very beginning. Evidently, the costs of the distribution network and the heat losses from it do not essentially depend on the number of customers. Starting with a connection degree of 50 % it is fair to say, that the size of the network would be the same, but with fewer connections, i. e. lower heat line density. Because future connections can be expected, the dimension of the pipes and the heat losses are given. Hence, the fixed cost per customer will decrease with the number of customers connected. Figure 9.7 shows an example.

Consider an area with 100 detached houses, each using 15 000 kWh per year. The pipes are loosing 20 % of the heat delivered to the customers, i.e. 30 0000 kWh per year. The value of this loss is 21 000 US$ (70 US$/MWh). Furthermore, it is assumed that 3 000 m trench make up the main distribution system at an average cost of 660 000 US$. The depreciation is for 20 years with an interest rate of 6 %. Finally the customer has to pay for service pipes and substation, totalling 4 500 US$, which adds 315 US$ on the annual fixed costs. From Figure 9.7 the annual fixed costs for each customer as a function of the degree of connection can be seen. The more customers are connected, the less the fixed cost per customer.

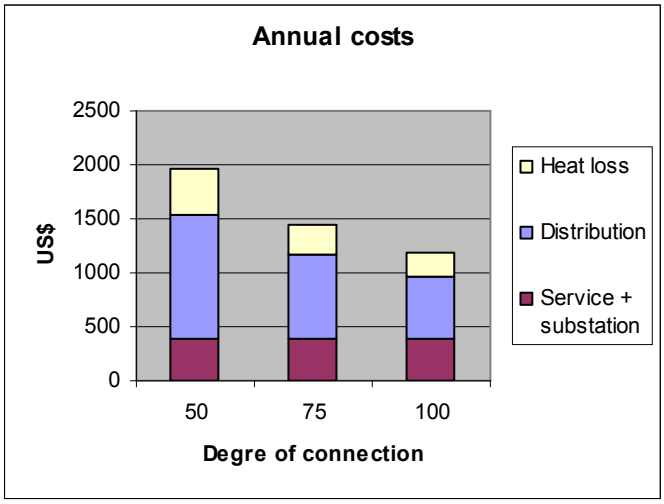

Figure 9.7: Annual costs for district heating connection as a function of customer connections.

Figure 9.7 also illustrates the importance of the marketing of the unique opportunity of initial connection, which only holds over a certain period. Let us say that 75 % is the calculated degree of connection. The marginal income per year for one extra customer for the utility will be in our example 900 US$ plus the profit from the sold heat, which could be as much as 150 US$/yr. Hence, each potential customer of the area to be connected could in our example be worth a marketing effort of at least 2000 US$ in to order to get him connected. The more connections, the higher the profit for the utility, or the lower the possible fixed costs to the customer, depending on the market situation; (it should be mentioned that the competitors for heating of detached houses, such as vendors of pellet furnaces (boilers) or heat pumps are also active and that each lost customer is then lost for many years). Sometimes, utilities are buying off older heating devices such as oil boilers from potential customers in order to get them connected from the very beginning.

On the other hand, the additional costs to be connected later on after the network has been built can be very expensive for a house owner. The reason is that a single additional connection job entails activities such as planning and providing information for the public, shut down of the network, pressurising and testing, but especially also providing the digging and working equipment, and the organisation of many people for a little job. Utilities are estimating between 5000 and 6000 US$ extra for a single additional connection and as a minimum, extra costs of 3500 US$ must be calculated according to Sandberg (2003).

10 Conclusions

This report gives an overview about the important measures to reduce the cost of connection to district heating in areas with low heat demand density, such as detached houses. The main purpose of this report is to give a state of the art review based on the experience in the participating countries of this project, i.e. Denmark, Finland and Sweden. The work is at first hand based on experience from planning and executing new projects. However, the first preinsulated networks were in use in the late 1960'ies and thus many old systems are now also in need for renovation. The recommendations given here for better design and reduced heat losses in new DH systems are of course also valid for the renovation of old systems.

This experience stems partly from the participants' own work and partly from development programmes that were recently carried out in these countries. For instance, the Programme of the Swedish District Heating Association "Värmegles Fjärrvärme" (Sparse district heating, 2007), was active between 2004 and 2007 and produced some forty reports dealing with techniques and methods for sparse district heating. Furthermore should be mentioned the work of the Danish Energy Administration (Energistyrelsen) as it was carried out by Kristjansson et al., 2004 and the R&D programme by the Danish District Heating Association, Kristjansson et al., 2005. In Finland, Fortum O.Y. was building and evaluating an area with detached houses from which we received actual input.

The reason for these activities was the traditional view that the connection of small houses is not a profitable business for district heating companies. For lack of better business, this view has changed and instead effort has been placed on techniques and measures, which could help to reduce costs. Expressed in terms of heat densities, we think that areas with a heat density of 10 kWh/m^2 (ground surface) or with line heat densities of 0.3 MWh/m,yr can fairly well be supplied by district heating.

Based on a number of projects, it was found out that district heating - in order to achieve good economy for low heat demand density - (also called here sparse district heating) needs more careful planning than traditional district heating. In many cases, alternative solutions that do not follow traditional district heating manuals can be successfully applied and will give lower costs. Some of these alternative solutions, of course, can in the future find their way into handbooks for heating with low heat line density, but some must - for the time being - be considered as odd measures and analysed carefully before being applied. However, local structures, commonly used methods and the availability of experience are more important for low costs than sophisticated methods which are applied without experience. Hence, in the following, we present some main conclusions, but as recommendations, they should be followed with caution.

The following provisions have been found to affect the total costs of the connection:

System design

- Examples from Denmark have shown that *low pressure and low temperature systems* with direct connection of a radiator system can reduce costs. Such systems can either be used in small local networks or as secondary systems, connected by heat exchangers or shunts to the main district heating system.
- System design for *reduced pipe dimensions* are strong drivers for systems supplying detached houses. Such systems can be systems with *hot water accumulators* instead of directly connected heat exchangers, or service pipes with reduced diameter and a *booster pump* for peak heat demand. The results for systems with hot water accumulators are ambiguous. In some locations, they can be advantageous, in other not. Booster pumps can in many applications help to reduce costs.
- House-to-house connection is already a well-demonstrated way to connect detached houses. However, it is difficult to get customers interested due to the larger impact on their premises. On the other hand, the combination of low system costs and rewards for own work makes it possible to sell this way of connection, especially in housing-cooperatives.
- The *degree of connection* is an important issue for both the utility and the customer. Since the costs of the distribution system (excluding the service pipes) and its heat losses are independent of the number of customers connected to system, the fixed costs are decreasing

with the number of customers. This leads to the following conclusion when planning a new network: *Invest in marketing and distribution of information from the beginning.*

District heating pipes

Pipes have a two-fold impact on the system costs: *Investment and heat losses*. All measures that can reduce these are of interest, such as good *insulation performance* and *advanced pipe design.*

- The thermal conductivity of polyurethane insulation depends on temperature as well as on the time elapsed since the foam was produced (ageing) and we discuss how a representative value of the thermal conductivity can be determined. Heat loss and the heat loss coefficients can be calculated for single, twin and triple buried heating pipes.
- New type of pipe systems are compared with respect to their possible installation costs and heat losses. *For a 80 mm (nominal) distribution pipe* we compared a pair of single pipes to a *circular twin pipe* and with an *egg-shaped twin pipe*. We found that the egg-shaped pipe reduced the heat loss by 37 % and the investment index by 12 % compared to a pair of single pipes.
- For the *service pipes* a pair of single pipes ø 25/77 mm is the reference case. We found that the *triple pipe* reduced the heat loss by 45 % compared to the reference case and by 24 % compared to a *circular twin pipe*. The reduction in the investment index is 21 %. New alternative designs of service pipes, involving a combination of co-insulation, asymmetric insulation, and dissimilar dimensions of two or three media pipes have a saving potential of roughly 50 % compared to a traditional pair of pipes.
- Lowest system costs could be achieved with a triple pipe system (service pipes only), i.e. a design with two differently sized supply pipes, one of them used in the case of high hot water consumption.
- The amount of heat going from the supply line to the return line is an import factor in twin and triple pipe designs. In the case of a supply temperature of 80ºC and varying return temperatures, we found for the 80 mm distribution line that only when the return temperature is below 30ºC, the return pipe will receive more heat from the supply line than it looses to the surroundings.
- *Service pipes* should be as small as possible and no reserve capacity should be calculated for. This is also valid for the distribution pipes. Taken future energy saving measures into account, reserve capacity should only be taken into consideration if it is obvious that new loads will be connected.

Civil Works

The classical trench design is for a pair of single pipes with a drainage bed. In accordance with local conditions, the trench can be made smaller with a corresponding reduction of excavation work and handling of earth masses. The following measures are possible:

- The use of twin pipes is mandatory in systems with low heat demand density. The reduction of excavation work is a clear costs advantage.
- Reduction of pipe dimension can possibly result in a smaller trench, which should be applied if possible.
- Reduced ground cover can be applied in piping without traffic loads. Hence, the routing should use such possibilities (parks, gardens, sidewalks).
- Drainage beds pipes can often be omitted, especially in trenches for service pipes.

New loads

District heating systems should be marketed to new customers with an *added value*: District heating can deliver part of the energy which so far was reserved to electricity. In the end, this could cover a broad spectrum of applications. In the beginning, new applications could be appliances such as *washing machines*, *dish washers* and *tumble dryers*. Small absorption cooling systems for air conditioning and heating of pools and hot tubs can be other applications.

An example is a demonstration of new loads in Gothenburg (Sweden). There it was shown that 7500 kWh of district heating could replace 5500 kWh of electricity. This application resulted in a 35 % reduction of primary energy (based on coal condensing power).

Evaluation and system analysis

A number of programs and calculation tools has been used in this project in order to analyse the consequences of a changed system design, system operation, pipe design and house loads. The analyses have been verified with system simulations, which showed a very high degree of accordance with measurements on the same systems (Neidonkallio and Nykøbing/Falster). The analyses compared the total cost for different pipe systems and district heating solutions, such as: Single pipes, twin pipes, triple pipes, reduced pipe dimensions, system with booster pumps in service pipes and systems with a hot water accumulator instead of direct hot water heat exchangers. From these analyses, the following conclusions can be drawn:

- Single pipes in dimensions < 150 mm should be replaced by twin pipes where possible.
- Pipe dimensions should be reduced so much that no capacity reserves are left (if planning for the future does not give a contra-indication).
- Triple pipes can well reduce heat losses and save costs.
- Direct connection can possibly reduce total system costs.
- House-to-house-connections may, in easily dug ground, lead to interesting cost reductions that should compensate house owners for the disturbance of their properties.

As to cost reduction, about 25 % in smaller systems (Nykøbing/F) and 40 % in larger systems (Neidonkallio) have been found among the investigated alternative system solutions.

11 References

Bøhm, B. (1984): Lavtemperaturdrift. *Optimering af nye fjernvarmesystemer (Low temperature operation. Optimization of new district heating systems).* Danish District Heating Association. ISBN 87-7367-032-4.

Bøhm, B.(2000): *On transient heat losses from buried district heating pipes*. Int. Journal of Energy Research 2000; 24:1311-1334.

Bøhm B., Frederiksen L., Christensen, K. P. (2005): *Forsøg med energirigtige stikledninger. Præsentation af forsøgsresultater (Energy-efficient service pipes. Report on a series of measurements).* Technical University of Denmark and Nykøbing Falster kommune. DFF F&U 2003-03. Danish District Heating Association, Kolding.

Bøhm, B., Kristjansson, H. (2005): *Single, twin and triple buried heating pipes. On potential savings in heat losses and costs.* Int. Journal of Energy Research 2005; 29:1301-1312.

Bøhm, B. Kristjansson, H. (2006): *Basic design optimisation of service pipes.* DBDH News 1/2006, pp. 8-11.

Claesson J., Bennet J. (1987): *Multipole Method to Compute the Conductive Heat Flows to and between Pipes in a Cylinder.* LUTVDG/(TVBH-709-3)/1-58/(1987). Department of Building Technology and Mathematical Physics, Lund, Sweden.

Cederborg, F. and Nordgren, O. (2005): *Mät – och värmeförluster för fjärrvärmesystem i småhusområden. (Measurement- and heat losses of district heating systems in areas with detached houses).* Swedish District Heating, FoU – 2005:130.

ClimateWell (2007): http://www.climatewell.com.

Fraile Fernández, A.: *Absorption Cooling System in low power applications.* Linköping University; Graduate Thesis 2007.

Fröling, F. (2004): *Hur värmegles kan den värmeglesa fjärrvärmen vara*? (2004): *Miljöaspekter på värmegles fjärrvärme med dagens teknik jämförd med villaoljepanna. (How sparse can sparse district heating be – Environmental aspects regarding sparse district heating based on todays techniques in comparison with an oil-boiler for detached houses).* In Swedish. Chalmers, Kemiteknik och miljövetenskap. Värmegles-FOU 2004:9.

Gudmundson, T., et. al. (2006-1): *Innovativ montage- och systemlösning för fjärrvärmeanslutning av villaområde – Huvudrapport (Innovative installation and system solution for connection of detached houses – Main report).* In Swedish. Report Svensk Fjärrvärme- Sparse District Heating. 2006:26a.

Gudmundson, T., et. al. (2006-2): *Kamförläggning med serviceskåp. (House-to- house connection of detached houses with extern branching chamber).* In Swedish. Report Svensk Fjärrvärme-Sparse District Heating. 2006:26b.

Gudmundson, T., et. al. (2006-3): *Villaanslutningar från förgreningskammare. (Connection of detached houses by means of extern branching chamber).* In Swedish. Report Svensk Fjärrvärme-Sparse District Heating. 2006:26c.

Hof, H. J.(1996): *The district Heating Kitchen.* Assoc. of Energy Distribution. Companies in the Netherlands, EnergieNed (1996).

Ikäheimo, J., Rämä, M. (2007): District heating network simulator. Internal dataprogram, VTT.

Jonson E. (2001): *Värmeförluster från fjärrvärmenät i småhusområden – Inverkan av rörgeometri och dimensioneringskriterier (Heat losses from district heating networks in areas with single family houses – Influences of pipe geometry and design criteria).* Licentiate thesis. Institutionen för Värme- och Kraftteknik, Lunds Tekniska Högskola. ISRN LUTMDN/TMVK-7046-SE.

Kristjansson, H., Bruus, F., Bøhm, B. et al. (2004): *Fjernvarmeforsyning af lavenergiområder (District heating supply for low energy density areas). Energiforskningsudvalg for produktion og fordeling af el og varme.* Marts 2004. 106p. Carl Bro as and Technical University of Denmark. ISBN 87-7475-315-0.

Kristjansson, H., Bøhm, B. et al. (2005-1): *Forsøg med energirigtige stikledninger (Test of energy-economic service pipes).* Nykøbing Falster kommune, fjernvarmeforsyningen. DFF F&U 2003-03. Danish District Heating Association. June 2005.

Kristjansson, H., Bøhm, B., Christensen, K.P. and Frederiksen, L. (2005-2): *Optimering af stikledninger (Optimization of service pipes).* Fjernvarmen 12/2005, pp. 28-33.

Kristjansson, H. and Bøhm, B. (2006): *Optimum Design of Distribution- and Service Pipes. Proceedings of the 10th International Symposium on District Heating and Cooling, Hannover, September 2006*. Also published in EuroHeat&Power – English Edition IV/2006, pp. 34-42.

Kristjansson, H. and Thorsen, J.E. (2006): *Cost Comparison: Storage Tank versus Heat Exchanger.* Proceedings of the 10th International Symposium on District Heating and Cooling, Hannover, September 2006. Also published in EuroHeat&Power – English Edition IV/2006, pp. 44-50.

Kristjansson, H. and Salomon, R. (2007 A): *Forbrugerinstallationer og ledningsnet – hvad er sammenhængen? (Consumer installations and network – what is the connection?)* Fjernvarmen 9, 2007, pp. 38-41.

Kristjansson, H. and Salomon, R. (2007 B): *Samtidighed for brugsvandsforbrug før og nu (Aggregation of hot water demands, past and present).* Fjernvarmen 8/2007, pp. 34-37.

Kristjansson, H. and Sonne, Peter (2007): *Samlet syn på ledninger og forbrugerunits (Joint View on Pipes and Consumer Units).* Fjernvarmen 11/2007, pp.36-39.

Kvisgaard B, Hadvig S. (1980): *Varmetab fra fjernvarmeledninger (Heat loss from Pipelines in District Heating Systems).* Teknisk Forlag; Copenhagen. ISBN 87-571-0635-5.

Larsson, L., Andersson S., Werner S. (2002): *Nuläge Vämegles Fjärrvärme. (Status of sparse district heating*). In Swedish. Svensk Fjärrvärme. FOU 2002:74.

Lindeberg, J - Svensk Fjärrvärme (2007): *Kulvertkostnadskatalog (Swedish Pipe system cost catalogue).* In Swedish. Svensk Fjärrvärme. Report 2007:1.

Logstor (2007): www.logstor.com

Pálsson, H. et al. (1999): *Equivalent models of district heating systems*. ISBN 87-7475-221-9. Energiteknik, DTU. Includes the DHSim User Guide.

Persson, T. (2007): *Dishwasher and washing machine heated by a hot water circulation loop.* Appl. Thermal Engineering 27 (2007), 120-128.

Pohl H. and Klingmann, M. (2006): *Nätutformning och Distribution (Net design and distribution).* In Swedish. Report Svensk Fjärrvärme- Sparse District Heating (2006:24c).

Ramboll (2006): *Varmeforsyning af nye boligområder – Konsekvenserne af de nye energikrav til nyt byggeri (Heat supply of new residential areas. Consequenses of new energy requirements for new houses).* EFP05. Ref. 0549516/K00126-2-JEML(2). May 2006.

Reidhav, C., Werner. S. (2007): *Profitability of Sparse District Heating (2007).* Paper prepared for publication. (Chalmers University).

Sandberg, E. (2003): *Vad kostar småhusanslutningen? (What does the connection of detached houses cost?).* In Swedish. Report Svensk Fjärrvärme- Sparse District Heating (2003:4).

Sandberg, E. (2004-1): *Fjärrvärme I småhusområden – Goda exempel (District heating for detached houses – Some good examples).* In Swedish. Report Svensk Fjärrvärme- Sparse District Heating (2004:5).

Sandberg, E. (2004-2): *Danska erfarenheter – fjärrvärme till småhus i Danmark (Experience in Denmark with DH supply for single family houses).* Svensk Fjärrvärme, Sparse District Heating 2004:7. ISSN 1401-9264.

Schmitt F., Hoffmann H. 1999. *New Ways of Installing District Heating Pipes. IEA District Heating and Cooling,* Annex V. Report 1999: T3.2. NOVEM, ISBN 90-5748-012-3.

Siwertz, R (2007): Internal communication. Telge energi AB.

SolarFrost information (2006): http://www.solarfrost.com/

Värmegles Fjärrvärme (2007): (Sparse district heating). http://www.svenskfjarrvarme.se/smahusguide?&lang=1&force_menu=1244.

Wallentén, P. (1991): *Steady-state heat loss from insulated pipes.* Thesis, Department of Building Physics, Lund Institute of Technology, Sweden. ISBN 91-628-0340-9.

Walletun, H., Zinko H. (2004): *Det fjärrvärmeanpassade småhuset. (Detached houses adapted to district heating).* In Swedish. Svensk Fjärrvärme - Värmegles 2004:8.

Wefels, P. (1994): *Anwendung und Erprobung mizellarer Reibungsminderer in Fernwärme-systemen – Abschlussbericht. (Applications and tests of micellar Friction Reducing Additives) - Final Report*. Fernwärmeverbund Saar, Vöklingen. April 1994.

Werner, S. (1997): *Fjärrvärme till småhus – Värmeförluster och Distributionskostnader (District heating for detached houses – Heat losses and distribution costs).* In Swedish. Svensk Fjärrvärme (Swedish District Heating Association). FVF-11.

Werner, S. (2001): *Rewarding Energy Efficiency: The perspective of emission trading.* Euroheat & Power – Fernwärme International 30(2001):9, 14-21.

Werner, S. (2006): EcoheatCool - Work Package 1: *The European heat market, Final Report*. Euroheat & Power, 2006.

Zegers, F.T.S, Molenbroek, E.C. (2000): *Field test of heat-fed washing machines and tumble dryers.* ECOFYS, Utrecht, 2000.

Zinko, H., Bøhm, B. (2005): *Värmeförluster i småhusområdet Prästmarken, Växjö. (Heat losses in an area with detached houses in Växjö, Sweden).* In Swedish. Svensk Färrvärme. 2005:126.

Zinko, H. et al (2006): *Avancerad fjärrvärmeanvändning i småhus - Demonstrationsprojekt fjärrvärmeanpassade småhus Göteborg. (Advanced district heating application for detached houses - Pilot project in Gothenburg).* In Swedish. Svensk Fjärrvärme - Värmegles 2006:29.

12 Appendices

APPENDIX 1

Methods for calculating steady state heat losses from buried distribution pipes

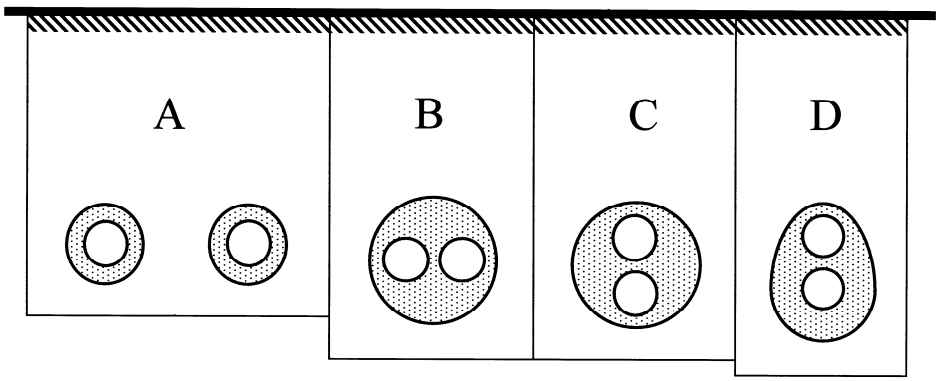

Figure A.1.1: District heating pipe systems. A: Pair of single pipes. B: Horizontal twin pipe. C: Vertical twin pipe and D: Egg-shaped twin pipe.

Steady state heat loss theory for buried heating pipes

In general, the heat loss equations will be in the following form:

$$\text{Pipe j: } q_j = \sum_{i=1}^{n} p_{ji} (T_i - T_g) \qquad (1)$$

where

n is the number of pipes
q_j is the heat loss from pipe j
T_i is the temperature of pipe i
T_g is the undisturbed ground temperature
p_{ji} are system constants (heat loss coefficients).

In case of two pipes:

$$\text{Pipe 1: } q_1 = U_{11} (T_1 - T_g) - U_{12} (T_2 - T_g)$$
$$= (U_{11} - U_{12}) (T_1 - T_g) + U_{12} (T_1 - T_2) \qquad (2)$$

$$\text{Pipe 2: } q_2 = U_{22} (T_2 - T_g) - U_{21} (T_1 - T_g)$$
$$= (U_{22} - U_{21}) (T_2 - T_g) - U_{21} (T_1 - T_2) \qquad (3)$$

U_{ij} is the linear thermal transmittance, or the heat loss coefficient.

If we can assume that the heat flow from pipe 1 to pipe 2 is the same as the heat flow from pipe 2 to pipe 1, $U_{12} = U_{21}$, then the system constants are reduced to three constants. If pipe 1 is the supply pipe and pipe 2 is the return pipe, then usually $T_1 > T_2$, and $U_{12} (T_1 - T_2)$ is the heat flow from pipe 1 to pipe 2. Although the heat transfer appears to consist of two "independent" heat flows, it should be remembered that the actual heat transfer is two- (or three-) dimensional.

In the case of twin pipes (two media pipes in the same casing) as well as single pipes of different dimensions, we need three system constants. In a typical case, the two single pipes are identical, placed horizontally and in the same depth from the ground surface. Then the system constants are reduced to two, $U_{11} = U_{22}$ and $U_{12} = U_{21}$. In this case, the total heat loss is calculated from

$$q_{tot} = q_1 + q_2 = 2 (U_{11} - U_{12}) \left[\frac{T_1 + T_2}{2} - T_g \right] \qquad (4)$$

The quantity 2 (U_{11} - U_{12}) is the quantity often supplied by the pipe manufacturers for horizontally placed identical single pipes. For other types of preinsulated pipe systems, U-values usually are not stated by the manufacturers.

For a triple pipe (3 media pipes in the same casing) we need nine system constants.

Pipe 1: $q_1 = U_{11} (T_1 - T_g) - U_{12} (T_2 - T_g) - U_{13} (T_3 - T_g)$

$$= (U_{11} - U_{12} - U_{13}) (T_1 - T_g) + U_{12} (T_1 - T_2) + U_{13} (T_1 - T_3) \quad (5)$$

Pipe 2: $q_2 = U_{22} (T_2 - T_g) - U_{21} (T_1 - T_g) - U_{23} (T_3 - T_g)$

$$= (U_{22} - U_{21} - U_{23}) (T_2 - T_g) + U_{21} (T_2 - T_1) + U_{23} (T_2 - T_3) \quad (6)$$

Pipe 3: $q_3 = U_{33} (T_3 - T_g) - U_{31} (T_1 - T_g) - U_{32} (T_2 - T_g)$

$$= (U_{33} - U_{31} - U_{32}) (T_3 - T_g) + U_{31} (T_3 - T_1) + U_{32} (T_3 - T_2) \quad (7)$$

However, this system can be reduced to six system constants, assuming $U_{12} = U_{21}$, $U_{13} = U_{31}$ and $U_{23} = U_{32}$.

Case A. Identical, circular, horizontally placed pair of single preinsulated pipes.

This pipe system is shown in Figure A.1.2. The U-values can be calculated with sufficient accuracy from analytical expressions, cf. for instance Bøhm (2000), bearing in mind the uncertainty associated with the material properties

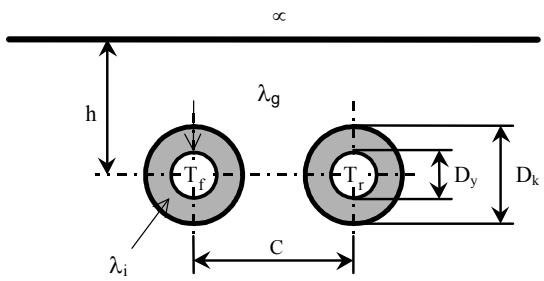

Figure A.1.2: Pair of single pipes.

Effective laying depth H:

$$H = h + \frac{\lambda_g}{\alpha} = h + 0.0685 \quad (8)$$

as the heat transfer coefficient at the ground surface α can be estimated to be 14.6 W/(m^2K), cf. Kvisgaard & Hadvig (1980).

Resistance of the insulation:

$$R_i = \frac{1}{2\pi\lambda_i} \ln\left(\frac{D_k}{D_y}\right) \quad (9)$$

Resistance of the ground:

$$R_j = \frac{1}{2\pi\lambda_g} \ln\left(\frac{4H}{D_k}\right) \quad (10)$$

Heat exchange between the pipes:

$$R_h = \frac{1}{4\pi\lambda_g} \ln\left(1 + \left(\frac{2H}{C}\right)^2\right) \tag{11}$$

R_h expresses the reduction of the heat loss caused by the other pipe heating up the insulation and the ground. For a pair of single pipes the term has minor significance, but for twin pipes (and concrete ducts with aerated concrete insulation) it has a significant effect.

$$U_1 = \frac{R_i + R_j}{(R_i + R_j)^2 - R_h^{\,2}} \tag{12}$$

$$U_2 = \frac{R_h}{(R_i + R_j)^2 - R_h^{\,2}} \tag{13}$$

CO-INSULATED PIPES

In general, no analytical expressions exist to calculate the heat loss from co-insulated pipes. For circular pipes, the Multipole method developed by Johan Claesson can be applied, Claesson & Bennet (1987). The method is available as a small computer program.

Case B. Circular twin pipes with horizontally placed identical media pipes.
This pipe system is shown in Figure A.1.3. In this case, an approximate solution to the Multipole method has been derived by Wallentén (1991).

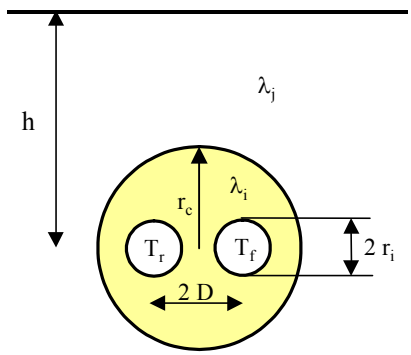

Figure A.1.3: Circular twin pipe with horizontally placed identical media pipes.

The heat loss is separated in a symmetrical and a anti-symmetrical case, which are treated separately as shown in the following Figure A1.4.

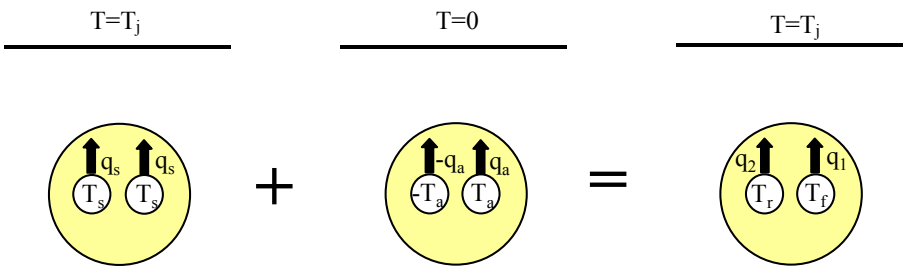

Figure A.1.4: The symmetrical and the anti-symmetrical case which when combined determine the heat loss from the buried pipe.

The heat loss from the symmetrical and anti-symmetrical case, respectively, is calculated from the following equations:

$$q_s = (T_s - T_j) * 2\pi\lambda_i * h_s \text{, where } T_s = \frac{T_f + T_r}{2}.$$

$$q_a = T_a * 2\pi\lambda_i * h_a \text{, where } T_a = \frac{T_f - T_r}{2}.$$

$$h_s^{-1} = \frac{2\lambda_i}{\lambda_j} * \ln\left(\frac{2H}{r_c}\right) + \ln\left(\frac{r_c^2}{2Dr_i}\right) + \sigma * \ln\left(\frac{r_c^4}{r_c^4 - D^4}\right) - \frac{\left(\frac{r_i}{2D} - \sigma * \left(\frac{2r_i D^3}{r_c^4 - D^4}\right)\right)^2}{1 + \left(\frac{r_i}{2D}\right)^2 + \sigma * \left(\frac{2r_i r_c^2 D}{r_c^4 - D^4}\right)^2}$$

$$h_a^{-1} = \ln\left(\frac{2D}{r_i}\right) + \sigma * \ln\left(\frac{r_c^2 + D^2}{r_c^2 - D^2}\right) - \frac{\left(\frac{r_i}{2D} - \gamma * \left(\frac{D * r_i}{4H^2}\right) + \sigma * \left(\frac{2r_i r_c^2 D}{r_c^4 - D^4}\right)\right)^2}{1 - \left(\frac{r_i}{2D}\right)^2 - \gamma * \left(\frac{r_i}{2H}\right) + \sigma * 2r_i^2 r_c^2 * \left(\frac{r_c^4 + D^4}{\left(r_c^4 - D^4\right)^2}\right)} - \gamma * \left(\frac{D}{2H}\right)^2$$

$$\sigma = \frac{\lambda_i - \lambda_j}{\lambda_i + \lambda_j}$$

$$\gamma = \frac{2 * \left(1 - \sigma^2\right)}{1 - \sigma * \left(\frac{r_c}{2H}\right)^2}$$

$D = C/2$, $r_c = D_k/2$, $r_i = D_y/2$.

If the resistance of the casing is to be taken into account, it must be included in the resistance of the insulation.

The heat loss coefficients U_1 and U_2 can be determined from the heat losses in the symmetrical and anti-symmetrical cases by:

$$q_f = q_s + q_a$$

$$q_r = q_s - q_a$$

$$\frac{1}{R_s} = (q_f + q_r)/2/(T_s - T_j) = q_s / (T_s - T_j), \text{ where } T_s = \frac{T_f + T_r}{2}.$$

$$\frac{1}{R_a} = (q_f - q_r)/2/T_a = q_a / T_a, \text{ where } T_a = \frac{T_f - T_r}{2}.$$

$$U_1 = \frac{\left(\frac{1}{R_s} + \frac{1}{R_a}\right)}{2} \text{ and } U_2 = \frac{\left(\frac{1}{R_a} - \frac{1}{R_s}\right)}{2}$$

Next the heat loss can be calculated by equations (2) and (3) for any combination of supply, return and ground temperatures.

Cases C and D. Other pipe systems (Circular and non-circular twin pipes, triple pipes)

These pipe systems are shown in Figures A1.1C and A1.1D. For circular pipes and casings, the Multipole method developed by Claesson and Bennet (1987), can be used to calculate the heat loss. However, in the general case the heat loss must be obtained by use of numerical methods, for instance the finite element method. In order to find the heat loss coefficients, different temperature sets must be used and next the n-equations with n unknown must be solved, cf. equation (1). Alternatively, the heat loss can be calculated for some temperature sets where U-values are obtained directly. For instance to find (U_{11} - U_{12} - U_{13}) in equation (5), the heat loss can be calculated for the case T_3=T_2=T_1.

How did we calculate the heat losses?

For simulation of transient temperatures in DH pipes it is necessary to know both U_1 and U_2, not merely ($U_1 - U_2$). Furthermore the simulation program should be able to take the heat capacity of the steel or PEX media pipes into account. In this work we have used DHSim, Palsson et al. (1999) and VTT (Ikäheimo, Rämä, 2007).

For vertical twin pipes U_1 and U_2 were calculated by the Multipole Method. For horizontally placed pipes a Matlab program was written, based on Wallentén's explicit equations (Wallentén, 1990). In cases where only $2(U_1 - U_2)$ is needed, for instance for system analysis, different programs are available. Often they are based on Wallenten's work, however, they only return the $2(U_1 - U_2)$ value.

"EkoDim" from the Swedish DH Association and Chalmers is one example of these programs. Similar programs are available from the Danish District Heating Association, the Danish Technological Institute, and Logstor. As the programs are based on the same equations, the results are very close to each other.

APPENDIX 2

Danish costs for different pipe systems for areas with low line heat density

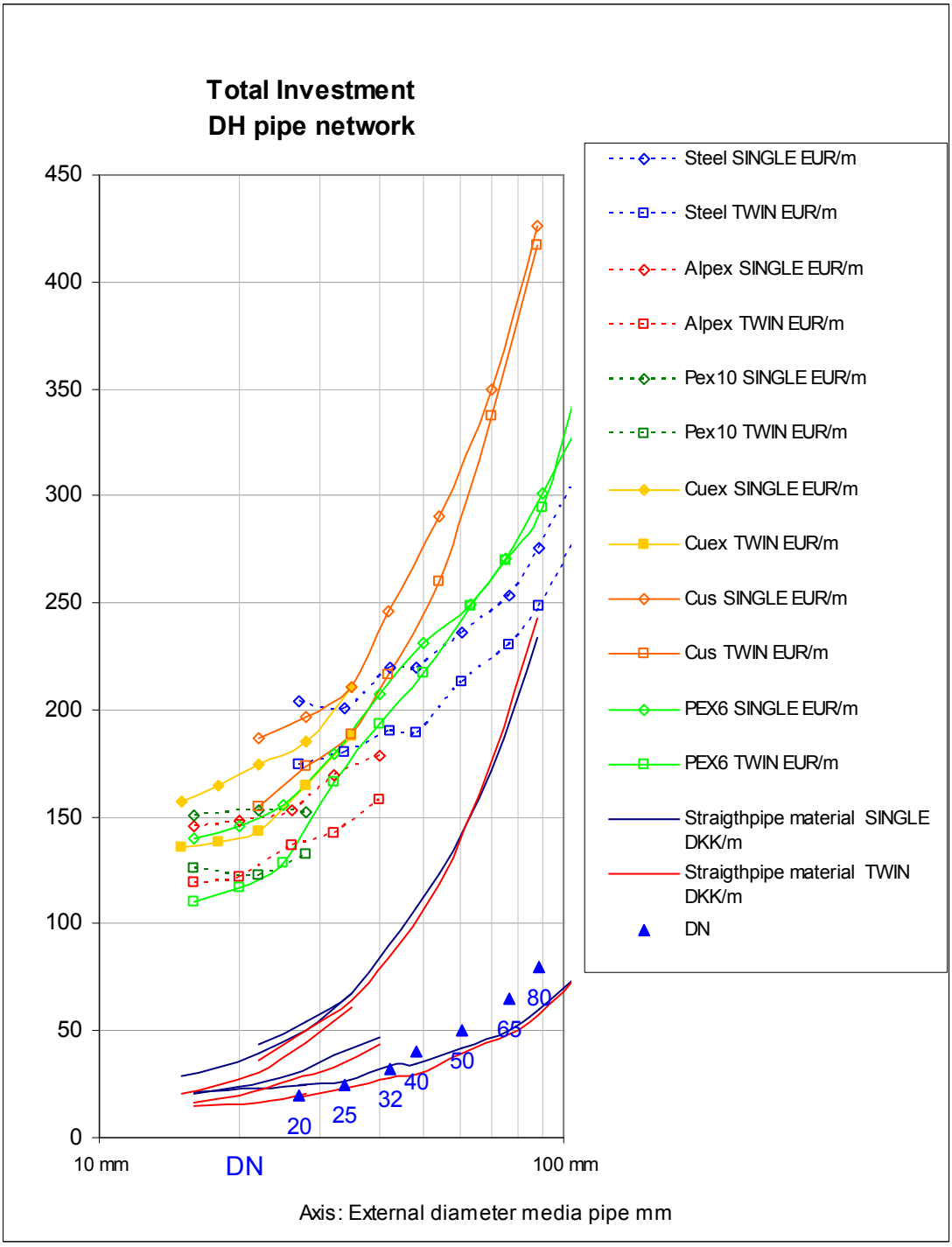

Figure A2.1: Pipe system costs for Steel, Cu and PEX-pipes for Denmark, 2007, gathered by Halldor Kristjansson.




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