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Including the Integration of CHP

Optimised District Heating Systems Using Remote Heat Meter Communication and Control

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Optimised District Heating Systems Using Remote Heat Meter Communication and Control

The contents of this report do not necessarily fully reflect the views of each of the individual participant countries of the Implementing Agreement on District Heating and Cooling, including the integration of CHP.

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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. As an element of the International Energy Programme, the participating countries undertake co-operative actions in energy research, development and demonstration.

District Heating offers excellent opportunities for achieving the twin goals of saving energy and reducing environmental pollution. It is an extremely flexible technology which can make use of any fuel including the utilisation of waste energy, renewables and, most significantly, the application of combined heat and power (CHP). It is by means of these integrated solutions that very substantial progress towards environmental targets, such as those emerging from the Kyoto commitment, can be made.

For more information about this Implementing Agreement please check our Internet site: www.iea-dhc.org/

Annex VI

In May 1999 Annex VI started. The countries that participated were: Canada, Denmark, Finland, Germany, Korea, The Netherlands, Norway, Sweden, United Kingdom, United States of America.

The following projects were carried out in Annex VI:

Title project	ISBN	Registration number
Simple Models for Operational Optimisation	90 5748 021 2	S1
Optimisation of a DH System by Maximising Building System Temperatures Differences	90 5748 022 0	S2
District Heating Network Operation	90 5748 023 9	S3
Pipe Laying in Combination with Horizontal Drilling Methods	90 5748 024 7	S4
Optimisation of Cool Thermal Storage and Distribution	90 5748 025 5	S5
District Heating and Cooling Building Handbook	90 5748 026 3	S6
Optimised District Heating Systems Using Remote Heat Meter Communication and Control	90 5748 027 1	S7
Absorption Refrigeration with Thermal (ice) Storage	90 5748 028 X	S8
Promotion and Recognition of DHC/CHP benefits in Greenhouse Gas Policy and Trading Programs	90-5748-029-8	S9

Benefits of membership

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

◯ District Heating and Cooling (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. The final materials from the research are tangible examples, but other benefits include the cross-fertilisation of ideas which has resulted not only in shared knowledge but also in opportunities for further collaboration.

Participating 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. The sharing of knowledge is a two-way process, and there are known examples of the expert him/herself learning about new techniques and applying them in his/her own organisation.

Information
General information about the IEA Programme District Heating and Cooling, including the integration of CHP can be obtained from:

> IEA Secretariat
> Mr. Hans Nilsson
> 9 Rue de la Federation
> F-75139 Paris, Cedex 15
> FRANCE
> Telephone: +33-1-405 767 21
> Fax: +33-1-405 767 49
> E-mail: hans.nilsson@iea.org
>
> or
>
> The Operating Agent
> NOVEM
> Ms. Marijke Wobben
> P.O. Box 17
> NL-6130 AA SITTARD
> The Netherlands
> Telephone: +31-46-4202322
> Fax: +31-46-4528260
> E-mail: m.wobben@novem.nl

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Introduction to the project "Optimised District Heating Systems Using Remote Heat Meter Communication and Control"

This report describes the results of the project "Optimised District Heating Systems Using Remote Heat Meter Communication and Control". The project has been carried out in co-operation with a project group comprising SINTEF Energy Research (Sintef) and Viken Energinett A/S (Viken) in Norway and the Energy Division of the Danish Technological Institute (DTI) in Denmark. DTI have acted as project secretary, administrator and manager. Participants in the project group have been Jacob Stang from Sintef, Rune Volla from Viken and Andy Drysdale from DTI. The contents of the report have been co-ordinated by DTI in co-operation with the project group.

At the outset of the project considerable interest from all the IEA member countries participating in Annex VI was shown in the project, resulting in all member countries appointing an expert to monitor the project. The members of the expert group have been:

- Tom Onno (Canada)
- Bjarne Lund Jensen (Denmark)
- Jaana Peltomäki and Mirja Tiitinen (Finland)
- Peter Kröhner (Germany)
- Seung-Kyu Ha (Republic of Korea)
- Arno Sijben and Harry Vreuls (The Netherlands)
- Tor Ingebrigt Hoel and Rolf Ulseth (Norway)
- Peter Dahl (Sweden)
- Richard Formby (United Kingdom)
- Doug Maust and Anders Rydaker (USA)

Jacob Stang, Rune Volla and Andy Drysdale
April 2003

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1 Summary and conclusion

The goal of this project has been to develop and test methods and algorithms, which will enable district heating operators to implement Demand Side Management (DSM) measures at consumer connection station level. Successfully implemented, these measures are expected to contribute to optimised district heating system operation. The methods involve the efficient use of remotely read heat meter data.

Consumer heating installations and systems are the main heat load source of a district heating system and therefore contribute significantly to the operation and efficiency of the total system. However, it is not common for the district heating operator to be able to monitor or control the operation of consumer connection stations. In the past, district heating operators have had limited access to data from consumer connection stations and district heating system operation was limited to providing sufficiently high temperature and pressure to all customers.

The widespread installation of electronic heat meters in individual consumer connection stations gives the possibility of providing accurate and detailed operational data about the connection station. Developments in electronics and communication technology have resulted in a range of remote reading systems for heat meters that can provide the district heating operator with useful operational data. Frequent remote reading of meters individually enables the operator to survey the operation of consumer connection stations and, in turn, to optimise heat production and heat planning processes, for example by applying DSM programmes.

It has almost exclusively been electric utilities that have introduced and increased DSM measures during recent years. These programmes are primarily designed to achieve peak load reductions. They have little effect on the total energy consumption, but instead smooth out peak loads. Peak loads are often a problem in district heating networks and it is expected that district heating suppliers can learn from experiences gained by the electricity sector.

In this project several methods and algorithms, aimed at allowing the district heating operator to implement DSM measures at consumer connection station level, have been developed and tested. An information study has been carried out to give an overview of the communication media currently available for remote reading systems and their applications. Conclusions have been drawn and some examples are given.

The reasons why peak loads occur are discussed and theoretical considerations for reducing this effect are addressed. Some promising strategies have been simulated and the results presented. To detect inefficient consumer connection stations data has been obtained from a number of test installations in Norway and the data has been used in a method to analyse connection station performance. The same measurement data has been used to test an algorithm to obtain a secondary forward temperature that minimises the primary return temperature from heating installations.

Finally, a method for continually monitoring a flow meter by comparison with a long-term stable pressure drop to check for deviations in measurement accuracy has been tested and evaluated.

The information study shows that the number of heat meters installed in district heating installations is expected to increase, as is the availability of communication systems capable of linking the heat meters to the district heating supplier or operator. This will allow the district heating supplier to use the metered data to carry out heating planning measures and provide valuable informative services for customers. Parallel development work is also under way on other district heating installation components such as pumps, valves and controllers. As these installation components become more intelligent and the individual devices become interconnected via a network, more measurement data from consumer connection stations and installations will be available. This data will provide an increased quantity of useful information becoming available to the district heating supplier.

The information study on meter communication concludes that:
- Current technology can provide communication systems capable of providing sufficient amounts of reliable, good quality data from the heat meter
- For communication between the district heating supplier and installed heat meters, data transfer speeds are sufficient with the currently available systems. The heating suppliers' planning requirements are not seen to be a driver for faster data transfer speeds.
- A heat meter is a good choice of communication device in consumer connection stations. As meter communication systems become standardised and readily available products, it should be a straightforward task to also use the meter to obtain additional installation data and information.

Some useful methods for reducing heat load at peak hours have been addressed. The results of investigations and simulations indicate that there is little potential for reducing the heat load used for hot tap water. For countries using mechanical ventilation with preheated air (commercial buildings, schools, hospitals etc.), there is the possibility of reducing heat load at peak times by employing a staggered start of the ventilation systems. This demands close co-operation and synchronisation between the end user and the district heating supplier.

The area seen to have the most potential for reducing heat load at peak times is the controlled short-time reduction of heating supply used for space heating. A range of simulations varying different operational parameters show that this method will have negligible effect on consumer comfort if applied for short periods of time.

Extensive field measurements carried out at three locations to detect inefficient connection station operation have shown inconclusive results, from which it has not been possible to detect any relation between the parameters investigated. The most likely cause is a combination of unsynchronised sampling times for the variables involved and errors occurring when comparing momentary measurement values with measurement values integrated over time.

The results of a two year surveillance test on the flow meter part of a heat meter have shown that the meter measures flow according to its specifications. The flow meter has been compared to an orifice plate flow meter installed in series with the heat meter. The meters only deviate slightly from each other for flow rates above 5 l/s where the differential pressure measurements have sufficient accuracy to be compared to the flow meter.

At the outset of the project which has formed the background for this report there was very little information and experience available about DSM in district heating systems. At the completion of the project there are signs of interest beginning to emerge but it must also be concluded that whilst DSM is an established mechanism for electricity utilities it remains in its earliest stage for district heating applications.

2   Introduction

2.1 Background

Consumer heating systems are a significant heat load
As the heat load source of a district heating system, consumer heating installations and systems contribute considerably to the operation of the total district heating system. Yet it is unusual that the operation of consumer connection systems can be monitored or controlled by the district heating operator. The optimal operation of the district heating system is therefore limited to providing district heating water with sufficiently high temperature and pressure to all customers connected to the supply network, without any possibility of optimising the system as a whole.

The development of computers and communication technology that has taken place during recent years has given rise to a rapid development in the possibilities for the district heating operator to survey the operation of consumer connection stations and/or heating systems by so called SCADA (Supervisory Control and Data Acquisition) systems. As prices continue to drop, the number of surveillance and fault detection systems installed in consumer heating systems is likely to increase, and become a natural part of any district heating system. These new and potentially powerful tools are, however, of limited value without a parallel development of algorithms and methods based on thermodynamics and heat transfer theory.

District heating meters and metering
Many countries with widespread district heating networks use electronic heat meters to meter heat consumption. In addition, there is a trend towards individual metering of heat consumption, i.e. the installation of a meter in each and every heating installation so that heat consumption can be billed individually. In Denmark, for example, where the district heating network supplies more than 50% of the population with space heating and hot water, heat consumption is metered - often on an individual basis – for billing purposes. There are currently more than 530,000 district heating meters installed in Denmark, and a survey carried out in 1998 [Drysdale, 1998] showed that electronic heat meters account for more than 80% of installed meters. This market share is expected to increase, as practically all newly installed meters are electronic heat meters. This is also the case in many other countries, where new district heating meters are almost always heat meters. Since the days of a person - the meter reader - visiting each meter installation to manually read the meter once a year developments in meter reading have included application of new technology and techniques, from hand-held devices to voice recognition and fully automated remote reading.

New communication possibilities
As remote reading systems become more commonplace, developments have also lead to other meter related applications. Two-way communication systems are emerging allowing messages and data to be sent to the consumer and vice versa. Current two-way communication systems for meter applications are still at a relatively early stage of development, but technology based on integrated microelectronics and information technology is developing quickly and there is a wide range of transmission media available. In the longer term, with an increased use of smart or intelligent components in heating installations, it is expected that it will be possible to use the meter as an active part of the heating installation as well as communicating with it.
Compared to the wide range of possibilities that modern communication technology allows, the remote reading systems that are currently available lag somewhat behind. [Lund, 2001]. The technical aspects of remote reading systems, data transfer from the meter to the district heating company's analysis and billing systems, work satisfactorily. However, there is still considerable room for improvement with regard to a greater level of informative feedback to the customer, including simple information about actual consumption and advice about what to do in the case of unsatisfactory operation, i.e. poor cooling. Technology is available for two-way communication, however this does not seem to be used much in district heating applications. A possible reason for this is that the personnel at the district heating plant already have a number of important systems to supervise which occupy them full-time and does not leave much time to attend to other matters. As district heating companies increase the level of automation in their operations they will have an increasing number of important systems to man and maintain, including their SCADA system, billing and finance system, piping and installation registration system etc. A successful remote

reading system or other communication system needs to be active and efficient around the clock, with regular back up, service and update of hardware and software. With the responsibility for ensuring that all the other systems are operative the added responsibility of maintaining a remote reading system can become a burden for the operators. In the future it can be expected that other systems, i.e. based on a wide use of the Internet, and operated by third parties will appear offering a wide range of new services for both the district heating company and the consumer.

Some district heating companies have taken up the challenge of giving their customers regular informative feedback and other added services based on metered data. An interesting example of these added services provided by a district heating supplier is an interactive Internet-based tool that is designed to help customers monitor and forecast their energy use [Anderson, 2001]. The Market Street Energy Company (an affiliate of District Energy St. Paul, Minnesota, USA) developed the system. In addition to providing the user with historical meter data the system allows the user to subscribe to a number of extra services, one of which allows the possibility of generating different reports, where the customer can bench-mark his or her data against similar customers. The system is discussed in detail in chapter 4.

2.2 Demand Side Management in district heating systems

Traditional district heating supply has been heating "on demand"
Historically the traditional operational philosophy of the district heat supplier has been to provide a constant supply of heat that at all times satisfies the heating requirements of the customer. Whilst fuel has been inexpensive and readily available, new plant has been cheap to build and finance. If at the same time the labour required for laying the piping system infrastructures has also been plentiful, the heat supplier can provide as much heat as the customer wants, whenever it is wanted, and at a low cost. If more customers are added to the district heating network, or existing customers increase their heating demand the heat supplier could simply increase output or build additional or larger facilities to supply more heat to accommodate the increased customer requirements. This form of operation, where heat is provided "on demand" can be called "Supply Side Management".

Demand Side Management as an alternative to Supply Side Management
Demand side management (DSM) can be regarded as a tool that can be used to find resources on the consumer (demand) side instead of on the supply side and as such can be seen as the opposite of supply-side management. In brief, DSM consists of utilities' planning, implementing, and monitoring of activities designed to encourage consumers to modify their levels and patterns of energy consumption. Generally speaking utilities implement DSM programmes to achieve two basic objectives: energy efficiency and load management. Energy efficiency is primarily achieved through programs that reduce overall energy consumption of specific end-user devices and systems by promoting high-efficiency equipment and building design. Energy efficiency pro-grams typically reduce energy consumption over many hours during the year. Load management programs, on the other hand, are designed to achieve load reductions; primarily implemented at the time of peak load. Load reduction programs have little effect on total energy consumption, but smooth out peak loads and reduce the need for specific fossil fuels to be used to cover these peak load demands.

Electricity utilities have been the driving force behind DSM energy programmes
It has almost exclusively been electric utilities that have introduced and steadily increased DSM programs during recent years. The aim has been to promote energy efficiency, and achieve cost effectiveness for both utilities and consumers. This has involved deferring the need to build new power plants or expand the supply infrastructure, by flattening load curves and constraining demand growth. According to [Vreuls, 1998], electricity utilities have undertaken enormous effort and expense to provide electricity "on demand". However, demand does not have to be treated as entirely outside the utility's influence and control. Utilities world-wide have developed innovative ways to influence both short-term and long-term demand, and to significantly reduce infrastructure costs in the process. DSM is one of these tools. More generally DSM can be looked

upon as a tool for society to make better use of scarce resources. By enhancing energy efficiency programs DSM can contribute to the conservation of fossil-fuel energy sources and a reduction of air emissions. DSM programmes deliver economic benefit by improving infrastructure utilisation through flattening load curves and/or by cost effectively reducing energy requirements whilst providing the same end-user benefit. For example the electricity utilities have encouraged consumers to install highly efficient lighting and ventilation systems and/or additional heat insulation. For the electricity sector different DSM programmes are already available and to focus on specific needs of different market segments programmes have been designed for residential, commercial and industrial sectors.

Typical DSM measures used by energy utilities
The implementation of DSM can be used to reduce load or to change the pattern of its use. However, the goal is to choose the best option to provide energy services at the lowest cost and without reduced comfort or level of service for the end-user. For example, reduced load can be achieved by the energy supplier providing the customer with better equipment that uses less power, whilst maintaining the same level of service. The pattern of energy use can be changed by applying straightforward, and operationally simple, time-of-use pricing (tariffs) to shift the load.

District heating can learn from the previous experience electricity utilities have had with DSM
With the escalating world-wide concern for sustainable development there is sharp focus on increased energy efficiency combined with a minimum of environmental impact from energy utilities. District heating suppliers have also recognised the need for increased efforts to address energy efficiency measures and to obtain better value for the capital that has been invested in their energy system. The traditional operational methods of supplying heat "on demand" is not as commonplace and there is a growing interest for new and innovative measures to increase energy efficiency and value for money.

When considering the introduction of DSM measures district heating suppliers can undoubtedly learn from the incentives that electricity utilities have implemented. DSM programs aimed at electricity end-users make have made use of information, subsidies, contracts, and tariffs to influence demand-side decision making. The main aspects of these measures according to [Vreuls, 1998] are shown in table 1-1: (page 12).

DSM programmes increase overall energy efficiency primarily by improving utilisation of the fixed infrastructure, and by introducing high-efficiency equipment. The programmes achieve their real economic benefit either by improving utilisation of the fixed infrastructure by flattening the load curve, or by improving energy efficiency.

Improvements in the use of the fixed infrastructure give important benefits, usually because an analysis of the distribution of costs involved with supplying a service (electricity or heat) show that fixed costs dominate. Fixed costs are building and maintaining the fixed infrastructure of generation, transmission and distribution facilities, and providing periodic billing and related services to all customers. Relatively little cost is determined by the amount of electricity or heat delivered. Examples from the electricity sector indicate that fixed costs can account for up to 88% of total costs. As the fixed infrastructure investment is determined by peak load requirements, DSM programs that reduce the peak load in relation to total consumption will enable more heat to be delivered with the same infrastructure investment, reducing the cost of providing the service.

Benefits related to energy efficiency rely on the simple argument that district heating end-users require a satisfactory level of comfort rather than the heat itself. So, more efficient consumer connection stations, heating systems, improved insulation, and other actions that can reduce energy usage while providing the same end-use benefit will be acceptable for the consumer. While these efforts may reduce the cost of heating the building they may however, not reflect on the price of the heat itself, which remains unaltered.

Similar to electricity supply, the supply of district heat is also an energy supply and DSM activities relevant to electricity activities relevant to district heating systems could be imagined.

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Table 1-1 The main aspects of DSM measures

For example, it may be possible that some of the DSM mechanisms developed by the electricity sector e.g. peak clipping, load shifting, reduced load growth, the flexible use of diverse energy sources etc. can be applied to the district heating sector.

In the electricity sector DSM measures are tailored to different categories of energy end-users: residential, commercial, and industrial. Normally, associated DSM programmes are designed for one of these three target populations, due to four significant differences: number of end-users, energy consumption per user, types of energy usage, and sophistication of energy management. So, for example, a DSM program that includes an energy audit by a manufacturing engineer combined with a customised energy savings proposal and financing program makes sense in an industrial environment, while it would not be cost effective in a residential environment. Similarly, a subsidy program that offered a fifty percent discount on up to three compact fluorescent lights could have a significant impact in residential usage, while making no observable impact for commercial and industrial users. Similarities can be found in the district heating sector, where the greatest impact of implementing DSM measures would be in commercial and industrial applications. These end-users usually have a significant individual heat consumption contributing considerably to peak load demand and exhibiting characteristic patterns of use that would be relevant to incorporate in a DSM plan. In addition, users of these installations and buildings usually have a high level of energy awareness and possibly already have implemented a degree of professional energy management.

Different international views about the use of DSM in district heating
It is important that implementation of DSM in the district heating sector results in a service providing benefits for all parties involved, from district heating supplier to end-user customer. In

this project several aspects of implementing DSM have been investigated, addressed and discussed, see chapters 5 to 8. Some of these measures include simply providing customers with data so that they can take appropriate measures of improvement themselves. Providing informative data to customers is a suitable service if the user has suitable energy awareness and is actively interested in system improvements, as is the case where the building installations are professionally managed. However, there is the risk that unless the energy installations are professionally managed the novelty of saving energy or altering behaviour wears off with time so that it is difficult to create a lasting effect. Indeed, sometimes the opposite occurs, and consumption slowly increases again. Information can be supplemented with the introduction of tariffs to encourage the consumer not to use heat at certain times of the day. Other measures described in the report lie at the opposite end of the scale from informative measures and can be classified as "radical" measures, i.e. where the district heating company has direct access to the customer's heating installation, or part of it, (at connection station level) and to some degree controls the operation of it. Some large district heating customers in Denmark have shown interest in such packages of services that include optimisation, service and day-to-day running of their connection stations by the district heating company. It can be expected that other actors, i.e. metering companies will likewise be interested in providing this type of service. However, it should be stressed again that the principle behind these ideas is that both the district heating company and the customer must benefit from the scheme and the different mechanisms, but it is also clear that different DSM measures will be acceptable for the customers in different countries.

The possibility for introduction of DSM services in different countries will vary widely, depending on the customer relations between district supplier and consumer and depending on consumer connection station conditions.

For example, in countries with widespread district heating such as Finland, Sweden and Denmark and in some countries with less widespread district heating such as Korea and UK the district heating company does not usually own or automatically have control over consumer connection stations. Any access to the connection station will require the permission and approval of the customer. In other countries such as Norway and Canada the connection station is owned by the district heating supplier, allowing easier access for the supplier.

In some countries DSM measures will initially be based on purely informative services. In other cases the district heating supplier will go to great lengths to participate in a dialogue with their customers to fully understand customer requirements and to create a service that is tailor-made for the individual customer. In this process, collection and analysis of data from district heating meters can be used as a valuable source of information about the customer and as an tool to help build services that comply with the customers profile. The customer is then free to accept or reject the offer from the district heating supplier. Even though optimisation of production and distribution of district heat is important, it is regarded as secondary to provision of the service that the customer wants. Once the customer has found a satisfactory service, the district heating company can then trim their production and distribution to be as efficient as possible.

There seems to be an increasing trend throughout the district heating sector for end-users to engage others to manage not only the supply of their heat but also the utilisation of the heat in their installations and buildings to secure a satisfactory indoor climate with acceptable level of comfort. This exerts pressure on the district heating companies supplying the heat, because if this is a service that they cannot deliver there will be others that can.

DSM seen as a new business area for district heating suppliers
During the project a wide variety of potential actions and mechanisms which could be implemented have been identified. These mechanisms range from actions, which are probably only suitable for a limited number of applications, to purely informative measures, which are suitable for wide scale implementation. Seen on a wider perspective these different measures can be regarded as a potential new business package or focus area that could be called DSM. The district heating supplier provides a range of services or schemes that are offered to the customer and the customer has the freedom of choice about whether to join the scheme or not. It is clear

that the most attractive option for the customer is any change that is implemented, that results in an economic advantage for the user, without any noticeable effect on the level of comfort.

In some cases improved energy efficiency may occur without the intervention of district heating suppliers or their plans for implementing DSM measures. Certain building owners may want energy efficient equipment or products installed because of efficiencies important to the owners, as opposed to their importance to the heating supplier to reduce demand.

With the continued increase in number of heat meters and widespread availability of communication systems it is reasonable to expect that the data quantity and quality available from communication with the meters will allow the district heating suppliers to use the data to carry out heating planning measures. At the outset of the project which has formed the background for this report there was very little information and experience available about DSM in district heating systems. At the completion of the project there are signs of interest beginning to emerge, but it can be concluded that whilst DSM is an established mechanism for electricity utilities it remains in its earliest stage for district heating applications.

2.3 Scope and goals

The objective of this project has been to develop and test methods and algorithms which will enable district heating operators to implement Demand Side Management (DSM) in consumer heating systems at connection station level. The methods involve the efficient use of remotely read heat meter data as a tool to implement DSM to optimise district heating system operation. This improves utilisation of the system in general and reduces costs, leading to a better total economy of the system benefiting all the involved parties.

In any typical district heating supply area the ratio of consumer installations divided between small and large installations usually follows a 80:20 relationship, where there are 80% small installations and 20% large installations. Small installations are for example single family houses and large installations are for example industrial users, office buildings, large blocks of flats, schools, hospitals, and other institutions. However, energy consumption typically follows the inverse ratio, where the comparatively small number of large installations account for 80% of the total energy consumption and the large number of small installations account for the remaining 20%. This distribution of installation types and energy consumption is believed to be generally applicable throughout the district heating sector, regardless of country.

The project has thus targeted large installations as being the most suitable for DSM measures. This gives the scope for influencing singular large energy users that load the heating network considerably with the subsequent possibility of achieving relatively large energy savings and/or the possibility to move larger loads. It also gives the possibility to identify relevant DSM measures that after successful implementation on larger installations would have a spin-off effect onto smaller installations. In larger buildings there is the advantage that there is either a professional caretaker or a buildings services contractor available with a professional interest in achieving optimised energy management and cost effectiveness. Owners or occupants of single family houses and apartments usually have limited energy awareness, interest in, or technical understanding of, their heating installation.

3 Future communication scenarios

The purpose of this chapter is to give a brief but illustrative view of a possible future scenario for communication with heat meters and the district heating consumer installations in which heat meters typically are installed.

Due to the interest in remote reading heat meters there is considerable experience and know-how available about communicating with meters and several systems are available as standard solutions. At the same time as meter communication systems have been developed a parallel development has been taking place with other installation components such as the valves, pumps, sensors and controllers that are commonly found in consumer connection stations. The rapid development of microelectronics and IT has resulted in a considerable interest in connecting these components via a common network. Through the network the components are able to share measurement data and operational information of common interest (i.e. temperatures, flow) or pass on relevant information to a central controller or an operator (i.e. error status). By establishing two-way communication the user or operator can read data and information from the installation and write to it, i.e. to change settings. The advantage for the user is a more robust and stable installation and the operator has the opportunity to receive detailed operational data regularly and provide a better service to the user.

Work carried out earlier in Denmark has suggested that the heat meter with the addition of integrated intelligence in the form of a controller would be the automatic choice of control tool to control the installation as a whole [DTI, 1998]. Trials were carried out on using the meter to control a valve and good results were obtained for using the meter/valve combination to carry out simple control functions. However, even though it does not seem to be the case for the near future that the heat meter will be a dominating control device, the heat meter is still a good choice of main communication link between the installation and the outside world, see figure 3-1.
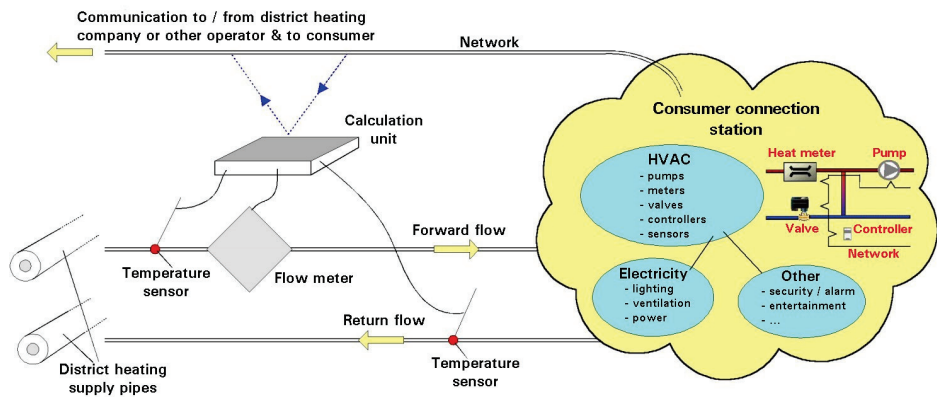
Figure 3-1 The heat meter as main communication path for the consumer connection station

In principle it would be possible to use any of the installation components as a communication link between the installation and the user, district heating company or other operator, but the heat meter is a suitable and natural choice. Suitable because of the many years of meter communication experience that already exists and natural because the district heating company is already interested in remote reading the meter at regular intervals and therefore methods of establishing a communication path are already known.

Meter data is basically limited to flow-rate and flow and return temperatures. Meter data supplemented with relevant data extracted from the connection station itself gives the user and the operator the opportunity to create a more accurate and detailed picture of the heating system. With the continued increase in number of installed heat meters district heating suppliers and operators will have a potentially powerful tool to aid them in carrying out heating planning measures.

There is no doubt that the information available from consumer installations will be of interest for many different third parties. A number of operators are interested in providing services for receiving, processing and transmitting data and it can therefore be expected that there will be a wide range of services available in the future.

4   Information study about meter communication

4.1 Historical developments

As mentioned in chapter 2, there has been a clear trend over the last decade or so towards individual measurement of district heat consumption, allowing heat suppliers to bill consumption individually. The search for a fair method of billing lead to the development of electronic heat meters as an alternative to volumetric meters and has resulted in installation of heat meters being common practice in most countries with a widespread district heating network. Work on improving district heating meters is ongoing and standardised. In Europe, for example, heat meters are standardised under the European standard EN 1434 [EN, 1434].

The traditional method of reading district heating meters has been a manual reading taken once a year, after which the annual bill is calculated and sent to the customer. Manual meter reading involves sending a person (the meter reader) from the district heating company to the customer to read the meter. This manual method is time and labour consuming with room for human error. First of all, the meter reader has to gain access to the meter. If the meter is installed indoors the meter reader has to visit the customer at the same time that the customer is at home, otherwise he has to make another call at a later time, typically outside normal working hours. Assuming the customer is at home, the meter reader then records the data from the meter by writing the relevant figures onto a form. Later, back at the district heating company's office, the same data is copied (usually by another person) to a computer database for use during preparation of a bill. Reading, recording, transporting and rewriting the data gives several opportunities for errors along the chain of operations, i.e. from reading the meter and during the transfer of information from one place to another.

Developments have resulted in the meter reader and his need for access to the consumer's installation being replaced by a variety of other methods. One solution is to use an outdoor data socket, which allows the meter to be read using a hand-held device and does not require the customer to be at home. Another method is to encourage customers to read their own meters and return the meter data to the district heating company either by post, on a pre-printed card or by telephone, where the data is transferred by push button or voice response. These meter-reading methods are inexpensive, but are characterised by still involving a large amount of manual work and administration and rely on continued customer co-operation and support. The methods are not regarded as suitable for using more than once or twice a year, making them limited with regard to regular and relevant feedback about the state of the meter or the customer's installation conditions.

A number of district heating companies have begun remote reading of their district heating meters and it is now quite common to be able to find complete systems of considerable size.

There are several advantages of remote reading heat meters. The need for a meter reader is removed as remote reading allows data to be transferred directly from the meter to the district heating plant. As data is transferred digitally the data is sent precisely and accurately, eliminating the errors commonly associated with manual reading and registration and eliminating the possibility of recording data for the wrong meter. Remote reading offers a range of advantages for both the district heating company and the customer. Meters can be read at a frequency that is free to choose, and at much shorter intervals than the traditional annual reading.

Regular meter reading also allows the district heating supplier to plan and optimise system operation. To calculate heat consumption electronic district heating meters measure flow and return temperature and flow. These basic measurements are of considerable value as they contain fundamental information that can be used to give a picture of the state of the consumer connection station, heating installation and its operation. The historic data stored in the meter can be used to compare consumption with previous periods or to compare with peer installations. Figure 4-1 illustrates the basics of a heat meter and the information that is available either by direct measurement or by calculation.
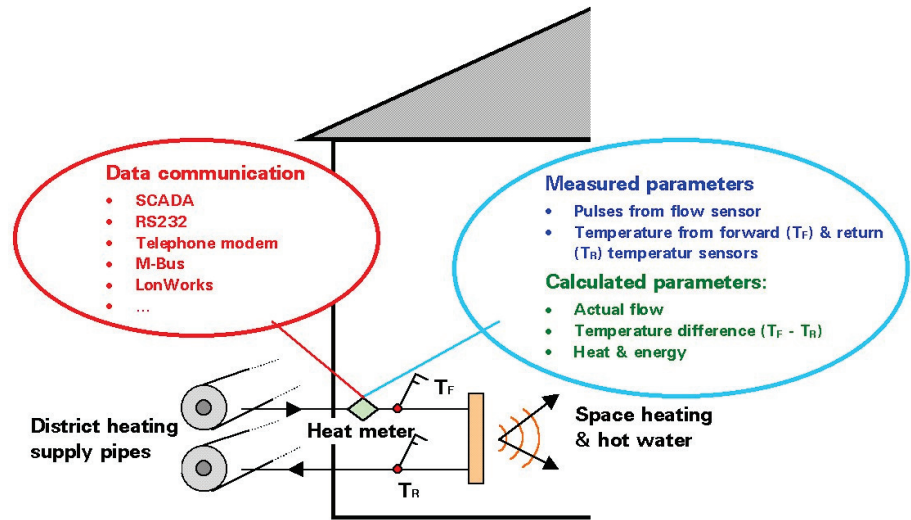
Data communication
- SCADA
- RS232
- Telephone modem
- M-Bus
- LonWorks
- …

Measured parameters
- Pulses from flow sensor
- Temperature from forward (T_F) & return (T_R) temperatur sensors

Calculated parameters:
- Actual flow
- Temperature difference ($T_F - T_R$)
- Heat & energy

District heating supply pipes

Heat meter

T_F

T_R

Space heating & hot water

Figure 4-1 Measured and calculated parameters from a heat meter

For example, by regularly reading the meters installed at the extremities of the supply pipe network it is possible to assess the distribution network's temperature distribution. With regular remote reading it also becomes possible to predict operational problems and to act accordingly before a problem occurs. Thus remote reading becomes a planning tool for assessing extensions to the existing network, pumping capacities, repair and maintenance work, heat production and heating planning etc. At the same time that regular meter reading allows the supplier to obtain a well defined picture of the heating network it also allows defect meters and other abnormalities in the consumer's installation to be detected. Defect meters can be replaced and the consumer can be informed if there seems to be a problem with his installation, (i.e. poor cooling) so that the appropriate action can be taken promptly.

4.2 Legal demands

In contrast to reading electricity meters, where some national demands require large consumers to have their meters remotely read at regular intervals, there are no current legal demands for remote reading of district heating consumption. The decision of whether or not to implement remote reading is left to the individual district heating company in collaboration with their customers.

Tariff systems vary widely between countries. Tariffs are usually made up of a combination of fixed cost and actual energy consumption but are sometimes based on actual energy consumption alone, without any fixed costs. In some cases the fixed cost is determined by subscription to a maximum installed effect or flow-rate. There is almost complete agreement throughout the member countries that in the future there will be increased focus on customers cooling of the district heating water and peak effect use. This is expected to lead to penalties for poor cooling and large peak effects. However, it can also be expected that district heating suppliers will provide incentives to improve cooling and control peak effects. In some countries penalties are already received if the average cooling (for example on an annual basis) is under a certain level.

4.3 Communication media

4.3.1 Wired, wireless and combined systems

Communication between meter, heating plant/supplier and customer can take place by a number of different means. Transmission media can be divided into wired and wireless systems. Wired systems include common twisted pair cables, coaxial cables, optical fibres and powerline (using electricity cables to transmit data). The wired telephone net was the first and most extensively used network, as it is simple to use and relatively cheap. Many district heating plants already have several years of experience with telephone based systems. Wireless systems include radio, infrared and microwave. The technology for using mobile telephones is available but is not widespread. With the advantages that wireless communication brings, as well as the general trend towards mobile telemetry, it is possible that these systems will become more competitive than traditional wired systems. Especially GSM and SMS (text message) based industrial data acquisition services are seen to have potential for applications in remote meter reading. Heat meter manufacturers have reported on increased interest and sales of GSM based system solutions and there are strong expectations for further increases.

Communication between meter and heating plant can be established either individually, i.e. via the telephone, or via a bus system which connects a number of meters. There are a considerable number of bus systems available on the market where the most commonly mentioned are M-Bus and LON. M-Bus (Meter Bus) is used almost exclusively for reading heat meters and has been included in the European Standard CEN 1434 "Heat Meters". Standardisation has meant that it is possible to mix different M-Bus products in the same net without conflict and as M-Bus is currently the most popular bus system for heat meters, the majority of heat meters currently on the market have built-in M-Bus connection capabilities. LON (Local Operating Network) from the American Echelon Corporation has allegedly the advantage of being able to use all forms of communication media.

The majority of current remote meter products are based on the wired telephone net. However, there are also a number of systems that apply a combination of wired and wireless technologies, where consumer data is internally transmitted via a wireless medium and externally transmitted via a wired system. This can be useful, for example, in a block of apartments where individual meter data is sent from the meters using a wireless technology to a local data acquisition system. The data is then sent out of the building collectively. In the case of installing individual meters in existing installations wireless technology has a considerable advantage over wired systems, as the need to lay or pull cables is not necessary.

A detailed description of wired systems and their applications and wireless systems and their applications is given in appendix 1.

According to many experts on communication a milestone in the standardisation work for communications systems has been the development of a common model that describes the general construction of a communications system – the OSI model. The OSI, or *Open System Interconnection* model defines a networking framework for implementing protocols in seven layers. Control is passed from one layer to the next, starting at the application layer in one station, proceeding to the bottom layer, over the channel to the next station and back up the hierarchy. A detailed description of the model is beyond the scope of this work, but the basic construction of the model and its layers is shown in figure 4-1.

Layer	Name	Description
7	Application	This layer supports application and end-user processes. Communication partners are identified, quality of service is identified, user authentication and privacy are considered, and any constraints on data syntax are identified. Everything at this layer is application-specific. This layer provides application services for file transfers, e-mail, and other network software services.
6	Presentation	This layer provides independence from differences in data representation (e.g. encryption) by translating from application to network format, and vice versa. The presentation layer works to transform data into the form that the application layer can accept. This layer formats and encrypts data to be sent across a network, providing freedom from compatibility problems.
5	Session	This layer establishes, manages and terminates connections between applications. The session layer sets up, co-ordinates, and terminates conversations, exchanges, and dialogues between the applications at each end. It deals with session and connection co-ordination.
4	Transport	This layer provides transparent transfer of data between end systems, or hosts, and is responsible for end-to-end error recovery and flow control. It ensures complete data transfer.
3	Network	This layer provides switching and routing technologies, creating logical paths, known as virtual circuits, for transmitting data from node to node. Routing and forwarding are functions of this layer, as well as addressing internetworking, error handling, congestion control and packet sequencing.
2	Data Link	At this layer, data packets are encoded and decoded into bits. It furnishes transmission protocol knowledge and management and handles errors in the physical layer, flow control and frame synchronisation. The data link layer is divided into two sub-layers: The Media Access Control (MAC) layer and the Logical Link Control (LLC) layer. The MAC sub-layer controls how a computer on the network gains access to the data and permission to transmit it. The LLC layer controls frame synchronisation, flow control and error checking
1	Physical	This layer conveys the bit stream - electrical impulse, light or radio signal – through the network at the electrical and mechanical level. It provides the hardware means of sending and receiving data on a carrier, including defining cables, cards and physical aspects. Fast Ethernet and RS232 are examples of protocols with physical layer components.

Figure 4-1 A simplified description of the OSI model

4.3.2 Using the Internet – a case study

As regards to supplying energy consumers with informative feedback, the Internet is expected to play a greater part as future communication system between the energy supplier and their customers. As mentioned in chapter 2 an Internet-based system has been developed in the USA [Anderson, 2001] and the system is described in the case study below.

Case study: Utilising the Internet to provide real-time feedback, monitoring and analysis of energy use. Implemented at District Energy St. Paul, St. Paul, Minnesota, USA.

District Energy St. Paul supplies district heating to 75% of the building space in downtown St. Paul. When the underground district heating pipes were initially installed, a conduit carry

metering communication wires was also installed, enabling communication with meters located throughout the network and data to be sent to a central computer on an hourly basis. The district heating company soon experienced that customers began asking for metered information on a regular basis. The customers found that the information could be used to ensure that heating installations in their buildings were running efficiently, to trouble-shoot equipment and to forecast consumption and budgets. This information was initially supplied manually but as the requests for information increased a more accurate and detailed tool was needed to meet customer demands. An energy analysis tool called ClearStory™was developed to provide customers with accurate and detailed meter data at high frequency rates (data is less than two hours old). The system allows customers to access any relevant information, including supply/return temperatures, energy consumption, load profiles, load comparisons, prices, water volume, flow rates etc. It is a secure system, with access protected by user name and password so that only authorised personnel can access the data. Depending on the subscription level the customer can create a number of different reports based on meter readings and outdoor air temperatures. Three service levels are available: Historical Metering Data, Benchmarking Tools and Analytical Tools. Each level offers progressively more complex and comprehensive information designed to give users the data they need to make energy decisions.

Level 1: Historical Metering Data
This level allows metered data to be viewed on a daily, monthly, or yearly basis. Using the data, it is possible to graph energy and water consumption, instantaneous energy demand and flow, and supply and return temperatures. There is also access to billing and account information. This level of service is supplied to all customers free of charge. A nominal charge is charged for higher levels.

Level 2: Benchmarking Tools
Level 2 gives access to all of the information in Level 1 plus the ability to view hourly metering data that are no more than two hours old. A range of reports based on meter readings and outdoor air temperature can be created, including load profiles, load comparisons, supply vs. return temperatures, energy consumption, cost per unit area etc. Results can be compared to energy consumption for previous years and benchmarked against buildings of similar size and type. In addition, it is possible to pre-configure up to five reports.

Level 3: Analytical Tools
In Level 3 users can segment all of the data available in Level 1 and 2 into hours, days, weeks, and months. Unwanted time periods can be filtered out, e.g. a report showing data from Monday to Friday can be created for the hours between 6:00 a.m. and 6:00 p.m. only. At this level it is possible to fine-tune heating and cooling operations during peak or off-peak hours daily, resulting in energy savings and lower operating costs.

Encouraging customers to continuously monitor their energy consumption and use gives a number of advantages. The following examples illustrate this:

Poor cooling
A customer felt that a building was not being heated as efficiently as could be. The data analysis tool was used to analyse several aspects of the system including supply and return temperatures. The graphs in figure 4-2 show that the return temperature was higher than normal, indicating that the heating system was not efficiently extracting heat from the district heating water. The problem could be traced to secondary heat exchangers and after cleaning these the return temperature returned to a normal level.
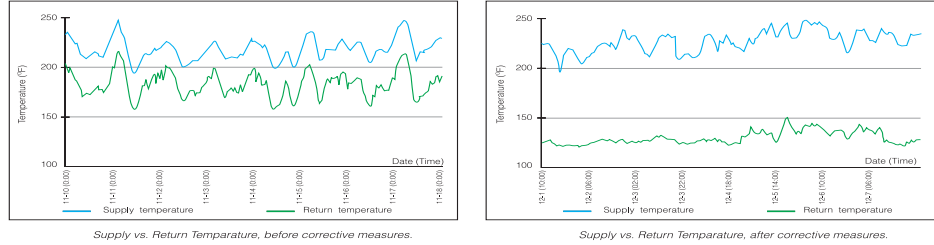
Figure 4-2 Example of improved cooling due to poorly performing components

Compensating for changes in efficiency
A customer had made a series of changes to the buildings energy management system and was interested in documenting the positive effect of these changes. By creating a load profile it was possible to show the customer actual energy consumption and trends for expected energy consumption vs. outdoor temperature, see figure 4.3.

1. Load profile, with inefficient energy management practices.

2. Load profile, with efficient energy management practices.

3. Load comparison, demonstrating positive effects of changes in energy management.
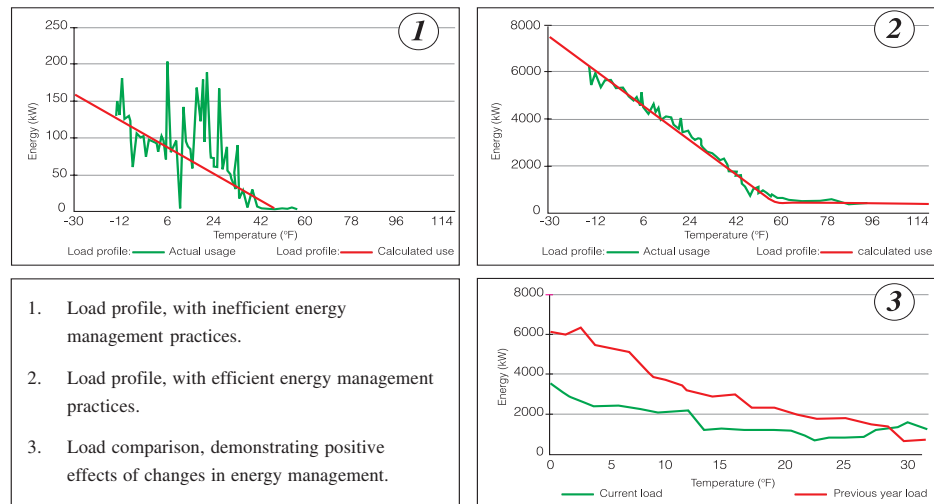
Figure 4-3 Comparing load profiles to demonstrate efficient energy management practices

By using the Internet and already available metering information this system demonstrates that customers can be encourage to operate their buildings more efficiently. With the help of useful, good quality information, customers can see how operational changes to their heating systems can save them money and help them troubleshoot defect or poorly performing components in their installation. In addition to saving the customer money the building occupants enjoy a higher level of comfort.

In the above examples only heating systems are discussed, however in the actual system services for both heating and cooling services are offered.

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4.4 Discussion and conclusions

Results from the information study indicate that the technologies used for remote reading are subject to constant change. The technology itself is being regularly improved and upgraded, new developments are taking place and technical barriers are being overcome. Some systems are well established and are readily available as standard solutions, i.e. telephone modem communication.

The following conclusions can be drawn from the information study:

- For DSM purposes current technology can provide communication systems capable of providing sufficient amounts of stable, good quality data cheaply.
- For communication with district heating meters data transfer speeds are sufficient with the currently available systems and DSM requirements do not need to push for greater data transfer speeds. Higher speed is also expensive.
- Focus should be on how to use the meter data and how to achieve savings and in particular how to provide useful informative feedback to users.
- The district heating meter is a good choice of communication device in customer connection stations. As installation components become more intelligent and individual components become interconnected via bus-systems (wired or wireless) more measurement data from consumer connection stations and installations can be expected to be available in the future. As meter communication systems are becoming standard and readily available products it should be a straightforward task to also use the meter to obtain additional installation data and information.

5   Methods for reducing heat load at peak hours

There are many reasons for the interest in reducing the heat load at peak hours in district heating systems. The most economically important contributions are:

❍   The investment cost for the distribution network
❍   The possibility to connect more customers to an existing network
❍   The cost of heat production

The focus on these different factors will vary from one company to another depending on local conditions.

From an economical point of view the investment cost in distribution capacity with very short utilisation time leads to consideration about how to reduce the peak load. In this connection the interest is to reduce the load at peak hours at extremely low outdoor temperatures.

As the size of a district heating network expands with time it will, at some time, reach the maximum possible heat load capacity. If it is possible to reduce the heat load at peak hours it will also be possible to connect more customers to an existing network.

The operational cost of a district heating system usually involves start and stop costs and the production price increases with the power output. It is therefore desirable to have as small variations in the load as possible.

In this project the technical measures for reducing heat load at peak hours by using the heat meter combined with control strategies have been studied. Peak load caused by night set back is not considered, as it is believed that the peak load contribution caused by night set back is best solved with tariffs.

5.1 Theoretical considerations

The peak load in a district heating network will behave differently to that in the electrical grid because the peak load in a district heating network results in both a flow peak and usually an increase in the temperature difference. The increase in the temperature difference is due to the use of hot tap water that usually occurs during peak load. The use of hot tap water decreases the average return temperature from the consumer connection station. Other connection stations can have a decreased primary temperature difference due to the onset of ventilation. The increase in the volume flow leads to a proportional increase in production load. The increased temperature difference is not seen at the production unit before the water with the decreased return tempera-ture returns to the production units.

It is therefore difficult to measure the instant load in a district heating network where the different loads have different influences on the return temperature.

As an example, consider ten district heating customers situated at different distances from the production unit. The customers all have a heat load of 5 kW with a primary temperature diffe-rence of 40 K (90 °C/50 °C) and, at the same time, a hot water consumption corresponding to 25 kW for 10 minutes with a primary temperature difference of 60 K (90 °C/30 °C). The instantaneous heat consumption in the district heating net would be 300 kW. The heat load seen from the production unit would be 217 kW, due to the increased flow. The temperature dependent part of the peak will arrive at the production unit as ten small peaks of 25 kW as shown idealised in figure 5-1.
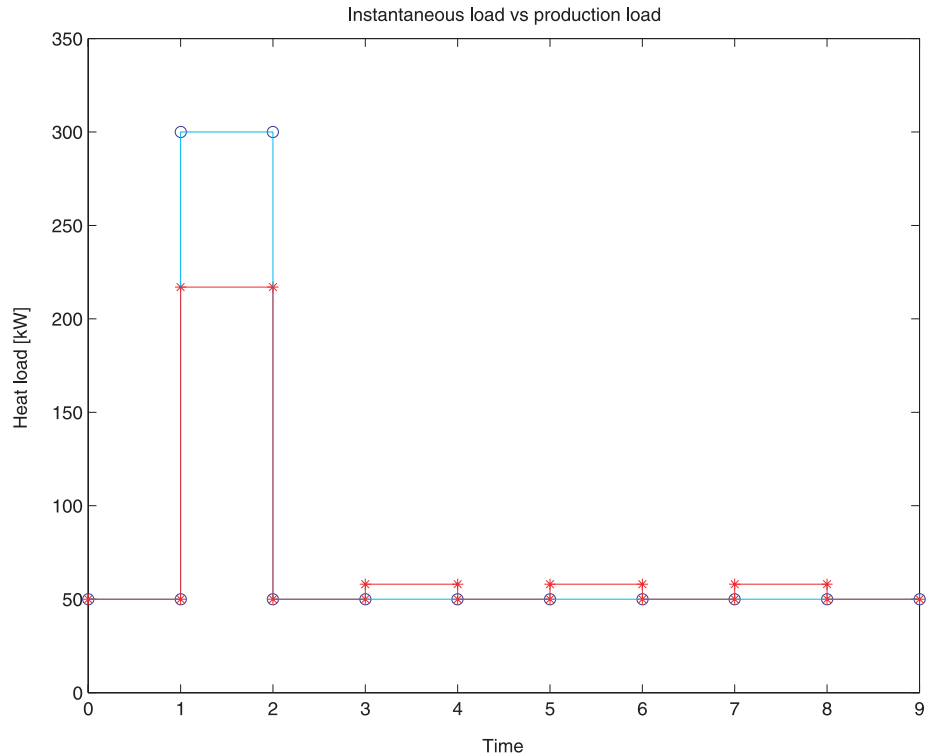
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Figure 5-1 Instantaneous load versus production load

5.1.1 The causes of peak hours in heat load

The heat load in a district heating network will mainly consist of three different uses of heat:
❍ Room heating
❍ Hot tap water
❍ Heating of ventilation air

In addition there could be industrial use of heat, swimming pools etc.

The use of mechanical ventilation with preheated indoor air varies considerably from country to country. In the Nordic countries it is common practice in commercial buildings, schools, hospitals etc. Since these types of buildings often dominate inner city areas, and district heating is most widespread in these areas preheating ventilation air can often account for a considerable amount of heat load.

In residential housing the use of ventilation with preheated ventilation air is quite uncommon in most countries.

In different kinds of buildings these three main uses of heat vary with time and the outdoor climate. It is the end users' influence on this that leads to peak hours.

This end user behaviour contributes to the peak hour load especially when the following activities coincide in time.

❍ Use of hot tap water in the morning hours
❍ The onset of room heating after night set back
❍ The onset of ventilation

These three loads most usually coincide in the early morning hours when many people use hot tap water in their homes, the buildings with night set back are brought back to normal operating temperature and the ventilation systems in commercial buildings are turned on in the morning.

The operation of heating systems is normally fully automated. There are several levels of automation involved. For a single family house the control system will usually compensate the flow temperature to radiators or other heat exchangers. The flow temperature is increased with decreasing outdoor temperature to increase the heating output due to a larger heating demand. With this compensation the secondary volume flow is held nearly constant when the heat load changes due to variations in outdoor temperature.

In buildings with large heat exchanger surface (radiators and the heat exchanger dividing the primary and secondary water systems) the secondary volume flow should ideally be lower than designed by the design temperature program and a resulting high secondary temperature difference. Correspondingly, the high secondary temperature difference combined with a large heat exchanger should give a high primary temperature difference.

5.1.2 Time relations due to peak consumption

The peak load in district heating systems can be viewed in different ways. The peak load can be the sum of the momentary heat loads of all the consumer connection stations. A constant primary temperature difference for all the connection stations will coincidence with the production heat load. This is not usually the case since the different heat loads have different secondary temperatures and thereby different effects on the primary temperature difference. I.e.

❍ Hot tap water heat load has a secondary inlet temperature below 10 °C
❍ Ventilation have forced convection and a "secondary" inlet temperature below 15 °C
❍ Room heating have natural convection with inlet temperature above 20 °C

Heat loads distributed in the network which increase the primary temperature difference will not be seen as an increase on the production side before the cooler water returns to the heat production plant. The heat load will also lead to an increase in the flow and this change in flow will be seen immediately as an increase in the heat load at the production plant. The temperature difference part of the heat load can be seen as a change of the energy stored in the distribution network. A decrease in the average temperature of the distribution network will represent a decrease in the stored energy. The decrease of the stored energy in the distribution network must be delivered back to the network.

Use of hot tap water in the morning hours is a typical heat load that increases the primary temperature difference and uses the energy stored in the distribution network.

The onset of room heating after night set back will typically give a high secondary volume flow and correspondingly a small secondary temperature difference and a high primary return temperature.

The onset of ventilation will often increase the secondary temperature difference and thereby decrease the primary return temperature.

5.1.3 Reduction of peak load

As mentioned in the 5.1.1 the causes of peak hours in heat load are due to loads occurring from room heating, consumption of hot tap water and ventilation.

In most cases (buildings without night set back) it should be possible to reduce the amount of heat for room heating during peak hours without notification of the end users. If the room heating is

turned off for short periods of time, i.e. an hour or so, it will only give very small fluctuations in the room temperature.

The dynamic heat balance for a room can be expressed as:

$$q = (\sum_i U_i \cdot A_i + c_p \cdot \dot{m}_{\text{inf}}) \cdot (T_I - T_O) + \sum_i m_i \cdot c_i \cdot \frac{dT_I}{dt}$$

Where:

q = Heat load [W]
U_i = U-value [W/m²·K]
A_i = Area [m²]
c_p = Specific heat capacity air [J/kg·K]
$\dot{m}_{\text{inf}}$ = Infiltration air flow [kg/s]
T_I = Indoor temperatur [°C]
T_O = Outdoor temperature [°C]
m_i = Mass [kg]
c_i = Specofoc heat capacity [J/kg·K]
t = Time [s]

The time constant is defined as:

$$\tau = \frac{\sum_i m_i \cdot c_i}{\sum_i U_i \cdot A_i + c_p \cdot \dot{m}_{\text{inf}}}$$

The room temperature after a reduction in room heating will then develop as:

$$T_I = T_S - \frac{\Delta q}{\sum_i U_i \cdot A_i + c_p \cdot \dot{m}} (1 - e^{-t/\tau})$$

For small buildings or buildings with homogenous conditions around the building it is possible to use this simplified room model for the whole building. For complex building or buildings with large variations in building structure a more detailed analysis is required.

The value of the time constant is 15 - 20 hours for lightly constructed buildings, from 50 - 100 hours for normal buildings and 100 - 250 for heavy constructed buildings.

For a complete stop of the heating systems the change in room temperature for a period of two hours is shown in Table 5-1. With a reduction of the heat load of 50% the values are halved.

T_O\τ	10	20	50	100	200
0	4.0	2.1	0.9	0.4	0.2
-10	5.8	3.0	1.3	0.6	0.3
-20	7.6	4.0	1.6	0.8	0.4

Table 5-1 Temperature difference for different time constants and outdoor temperatures

A normal building is assumed to have a time constant of 50 - 100 hours. By applying a 50% reduction in heat load it would be possible to reduce the space heating load for a period of two hours and change the indoor temperature by less than 1 K (outdoor temperature of –20 °C). This is a conservative estimate since the numbers imply that all the heat supply is turned off. In the real

case the heat from the heating system would be supplemented with internal gains from lighting, electrical equipment, people and solar heating.

It would be possible to reduce the set point for the hot tap water during peak hours but it is probably not a customer friendly or acceptable demand side management action. There are also hygienic considerations that must be taken into account before using this measure. The legionnaire bacteria is especially sensitive to water temperature level and a decrease in the hot tap water temperature can lead to a rise in legionnaires' disease.

Another measure to decrease the hot tap water contribution to the peak load would be to use hot water storage. However, hot water storage has a tendency to increase the return temperature of the primary water and the consequence could be that the heat load during peak hour is decreased, but the volume flow is at the same level during peak hours, and increased during the rest of the day.

The ventilation load is also difficult to reduce during peak hours in an acceptable way seen from the district heating customer's point of view. A decrease of the supply air temperature would immediately be noticed as a draught in the ventilated building. In large buildings with a large number of ventilation systems controlled by a SCADA system there can be problems when many large ventilation systems start up simultaneously. This start up combined with overshoot in supply air temperature and fluctuations can cause large local heat loads and also local hydraulic disturbances. In this case it would be possible to reduce the influence on the district heating network by a staggered start of the ventilation systems. This would not reduce the heat load during peak hours but it will give a smother and better operation of the district heating network. Whether this is an acceptable demand side management measure is a topic for discussion. The customer will have reduced influence on the start and stop of the ventilation plant and there can be questions about the energy cost for the systems that are started a little earlier and stopped a little later than the customer wants. At the Norwegian University of Science and Technology experiments have been done with respect to reducing the ventilation rate due to peak hours in the electric grid (to be reported). The heat demand in ventilation plants is almost five to ten times the power demand to the fans. For customers that are willing to reduce the ventilation rate during peak hours in the electric grid it is reasonable to believe that they also will reduce the ventilation rate due to peak hours in the district heating system.

The conclusion is that it would be possible to reduce the space heating heat load during peak hours. It could be possible to reduce the heat load to ventilation for some customers. There is little potential to be able to reduce hot tap water heat load.

5.1.4 Requirements and/or barriers

Based on section 5.1.3, "Reduction of peak load" the main conclusion is that the best way to achieve heat load reduction during peak hours is to base actions on a reduction of the heat load to space heating.

A reduction in hot tap water temperature is technically possible but not acceptable from, among other aspects, a hygienic point of view. It may also be undesirable from the customer's point of view. Although a large part of the hot tap water use in the morning arises from showers and baths, which do not demand particularly high water temperatures, some customers may want hot tap water for other purposes, i.e. washing or washing up, which demands a high tap water temperature.

For small customers it is common practice to use simple direct acting actuators. A reduction in hot tap water temperature will require an electrical actuator with an electronic controller, which will involve an added cost to the consumer installation.

The heat exchanger for heating and ventilation is usually a common heat exchanger. A reduction in heat load for room heating will thereby imply a reduction in the heat for ventilation if it is

applied on the primary side of the heat exchanger. This is not acceptable since the effect on the ventilation side would be undesirable. Alterations would require separate heat exchangers or a more complex control.

The relation between the heat load to space heating and the heat load to hot tap water is very small for single familiy houses. This implies that the reduction in the space heating load will be small compared with the heat load for hot tap water. For a single family house the relation would be:

$$0.2 < \frac{q_{space}}{q_{HTW}} < 0.5$$

Where q_{space}= 5 to 15 kW and q_{HTW} = 30 kW)

The heat load for space heating will increase proportionally with an increase in the heated area, whilst the heat load for hot tap water will increase with a lower rate. For five single family houses the relation between heat loads is:

$$0.5 < \frac{q_{space}}{q_{HTW}} < 1.5$$

Where q_{space}=25-75 kW, and q_{HTW}=50 kW)

For one single family house with a space heating load of 5 kW a reduction in space heating during hot tap water use will decrease the total heat load with 15%. For five single family houses with a heat load for space heating of 10 kW the reduction would be 50% provided that the space heating load can be reduced to zero during the hot tap water use. A more realistic value would be half the reduction.

The use of hot tap water is coincidental for a large number of customers connected to the network. If it is possible to reduce the space heating load during the use of hot tap water it should also be possible to reduce the space heating load for some period after use of hot tap water. Theoretically a reduction in space heating load only during the use of hot tap water would only mean a delay in the same peak load. It is therefore necessary to reduce the space heating load for a longer period to decrease the peak load in the distribution network.

The ventilation heat load and it's contribution to the peak load is not well suited for demand side management actions as described above. The improvements that can be achieved are more related to smoother operation of the distribution network and reduction of local phenomena related to the onset of ventilation. For buildings with many large ventilation systems a sequential onset of the different ventilation systems can reduce fluctuations in the hydraulic system. This requires large buildings with several ventilation systems controlled by a synchronised system or real two-way communication.

This leads to the following building categories and the possibility of reducing heat load shown in table 5.2.

	Hot tap water	Space heating	Ventilation
Single family	Not possible	Possible	Not applicable
Commercial building	Not applicable	Maybe possible	Possible

Table 5-2 Building categories and the possibility for reducing heat load

5.2 Simulation
The strategies described in section 5.1.3 have been tested in a computer simulation program for a two-stage consumer connection station. There are several possible methods to reduce the heat

load to the space heating system, including reduced secondary flow, reduced secondary flow temperature or reduced primary flow.

All the simulations are for a building with a time constant of 20 hours.

5.2.1 Reduction in secondary flow

One way to shut of the room heating system is to turn off the secondary circulation pump. As figure 5-2 shows it would not be possible to turn off the heating system for such a long period at design outdoor temperature.
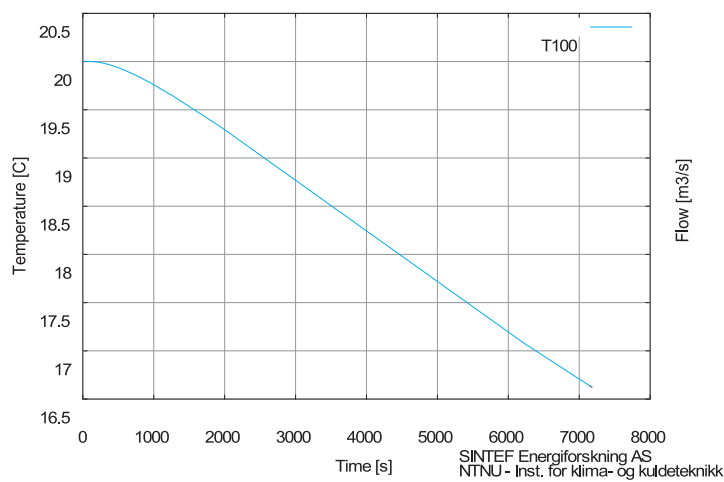
Figure 5-2 Simulation result for a building with a time constant of 20 hours and a two hour stop in heating supply at design outdoor temperature

By reducing the flow to the radiator system by 50% of the required flow, the temperature difference in the radiator system will increase with 50% and the effective power reduction in the room heating system will be approximately 25%. The decrease in the return temperature from the radiator system will, combined with the reduction in flow, result in a reduction in primary flow of 30%. The room temperature for this simulation is shown in figure 5-3.
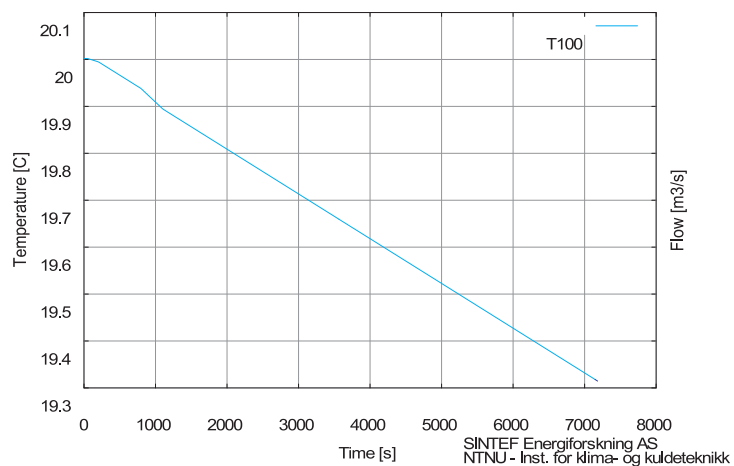
Figure 5-3 Simulation result for 50% reduction in secondary flow

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5.2.2 Reduction in secondary supply temperature

Reduction in secondary supply temperature from the design value of 80 °C to 60 °C results in a secondary heat load of 65% of the design heat load. The reduction in secondary return temperature gives an increase in the primary temperature difference and thereby a reduction in primary flow of 45% compared to the design conditions. The room temperature for this simulation is shown in figure 5-4.
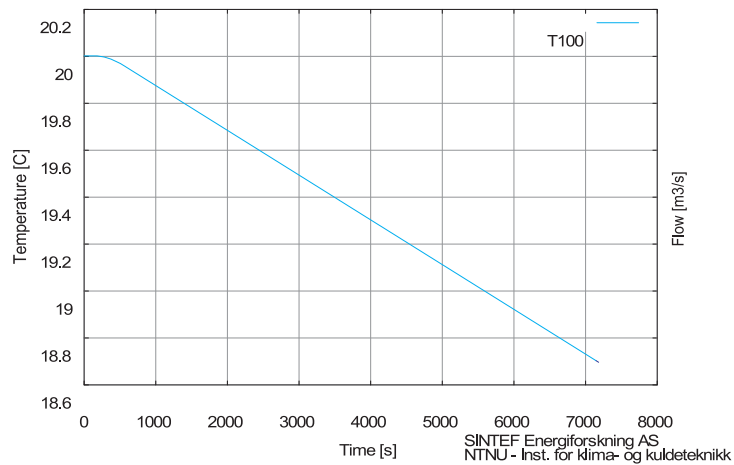

Figure 5-4 Room temperature with reduction in secondary forward temperature (80 °C – 60 °C)

5.2.3 Reduction in primary flow

A reduction in primary flow will have the same effect as reduction of the secondary forward temperature. An advantage of making the change in primary flow is the predictable reduction in primary flow. Another advantage is that the flow is kept constant during the reduction in heating. With reduction of secondary forward temperature the valve will close in the initial phase causing a more rapidly decrease in room temperature. The room temperature for this simulation is shown in figure 5-5.

A 50% reduction of primary flow compared to design flow gives approximately the same heat supply to the room as a reduction of secondary forward temperature from 80 to 60 °C.

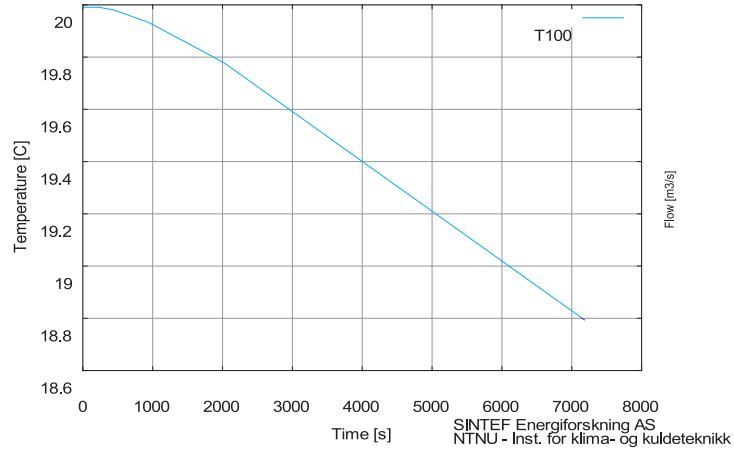The difference in the initial phase results in a slightly higher room temperature.

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Figure 5-5 Room temperature with 50% reduction of primary flow.

5.3 Discussion and conclusions

The simulated cases all show a decrease in room temperature. The question is how acceptable it would be to let the room temperature decrease. In normal temperature comfort considerations an optimum indoor temperature will have an acceptable range of ± 1 K.

A complete stop of the heating system will be possible for less than 1 hour and would not be recommended.

A reduction of the secondary flow to 50% of the design flow will keep the room temperature less than 1 K under the desired value for approximately 3 hours. A variation of the room temperature of less than 0.5 K is possible for 1.5 hours with this kind of control of the secondary flow. At the same time there will be a reduction in the secondary return temperature that again will give a reduction in primary return temperature.

Reduction in secondary supply temperature will be possible for 1.5 hours assuming that a 1 K decrease in room temperature is acceptable and there is also a decrease in primary return temperature.
Reduction of primary flow gives the same effect as reducing the secondary supply temperature.

The main difference between these control strategies is the physical location for installing the control application. The control strategies that involve the secondary side would usually not be feasible for the district heating company since the heat exchanger very often is the boundary between the district heating company and the building owner. The best opportunity is therefore to decrease the primary flow rate to the heat exchanger for room heating.

6 Detection of inefficient consumer connection stations

6.1 Field measurement

To test and implement the different strategies for using two way heat meter communication two different measurement programs have been carried out (measurement programme 1 and 2).

Measurement program 1 was intended to test and implement the use of two way heat meter communication to:

○ Detect inefficient connection stations
○ Adaptive control of secondary supply temperature

Detection of inefficient connection stations can be regarded as a simple one-way communication task if the heat meter has instructions to send data to the operator at pre-arranged time intervals. Any operational abnormalities would be revealed during periodic checks. The main advantage of two-way communication is the greater degree of freedom available to the operator, which he can use to request more frequent or detailed information as and when desired. Combined with the availability of higher data transfer speeds and greater bandwidth the heat meter then becomes a powerful tool to routinely transmit extra data that can be used selectively by the operator and/or the central utility.

Measurement program 1 was carried out at three consumer connection stations, denoted A, B and C respectively, located at the Norwegian University of Science and Technology in Trondheim. The following variables were measured in each connection station on an hourly basis:

○ Secondary supply temperature
○ Heat load
○ Volume flow

In addition the common primary supply temperature and the common outdoor temperature were measured.

The measurements were carried out using the existing installed control equipment and the collection of the data was done through the ordinary SCADA system.

The measurements have been collected from 9 January 2001 to 13 April 2002.

Measurement program 2 was a long term heat meter surveillance test done at an office building at a location outside Oslo. In this measurement program only the volume flow through the heat meter and the volume flow through an orifice plate flowmeter are measured. These measurements were carried out using a time resolution of 10 seconds.

6.2 Measurement results

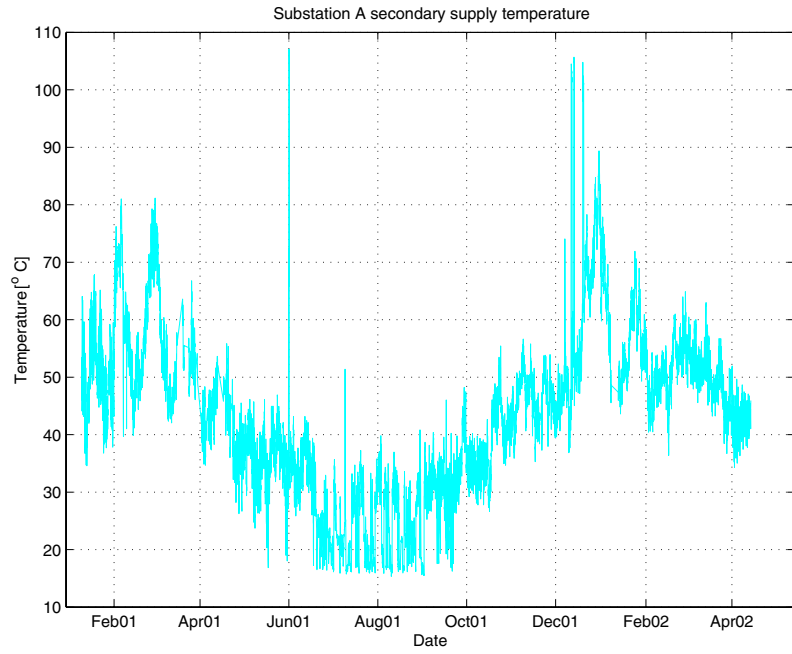The measurement results from the Norwegian University of Science and Technology are shown in figures 6-1 to 6-9.

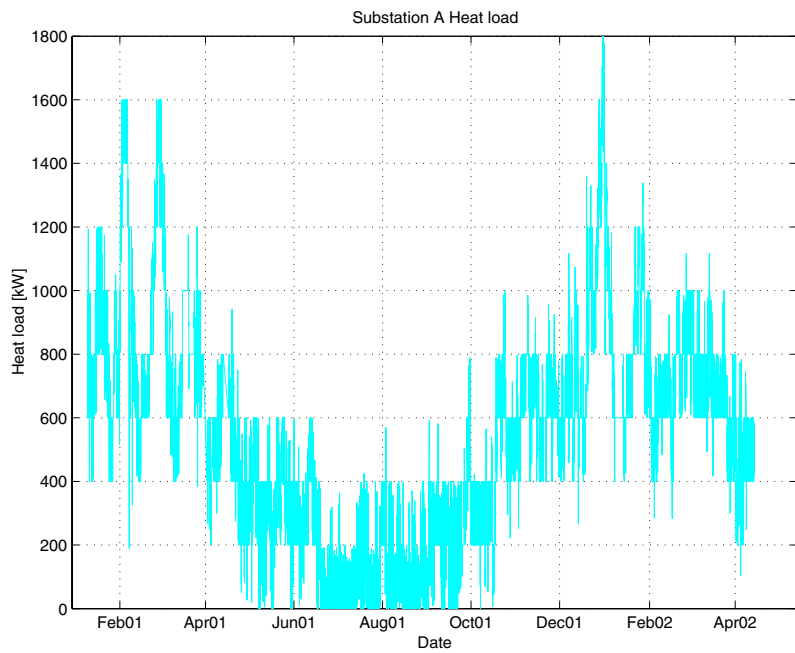*Figure 6-1 Connection station A: Secondary supply temperature*
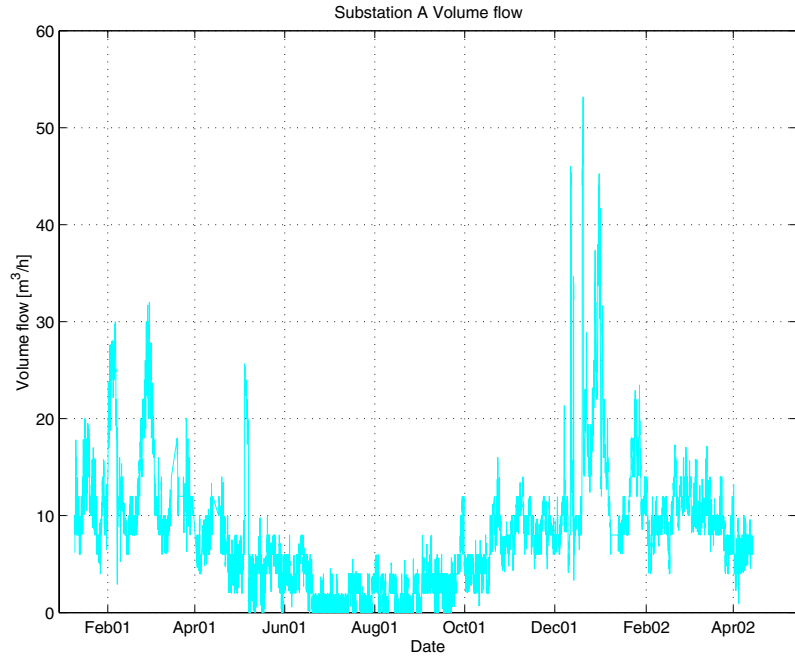

Figure 6-2 Connection station A: Heat load
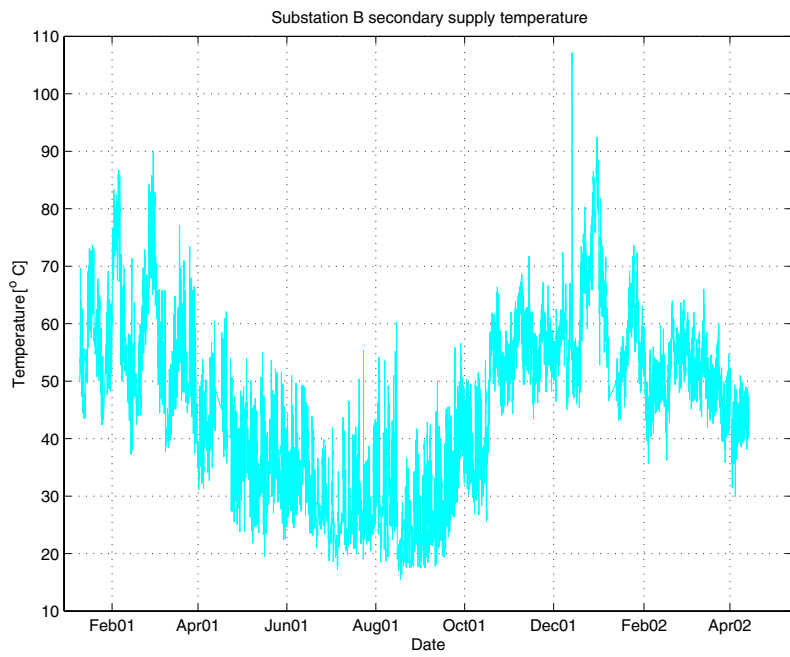
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Figure 6-3 Connection station A: Volume flow rate

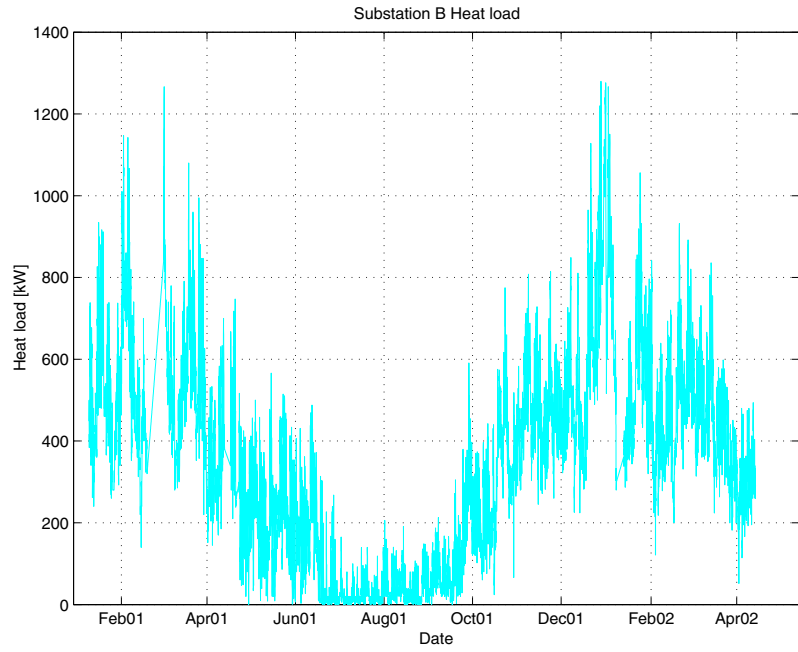*Figure 6-4 Connection station B: Secondary supply temperature*

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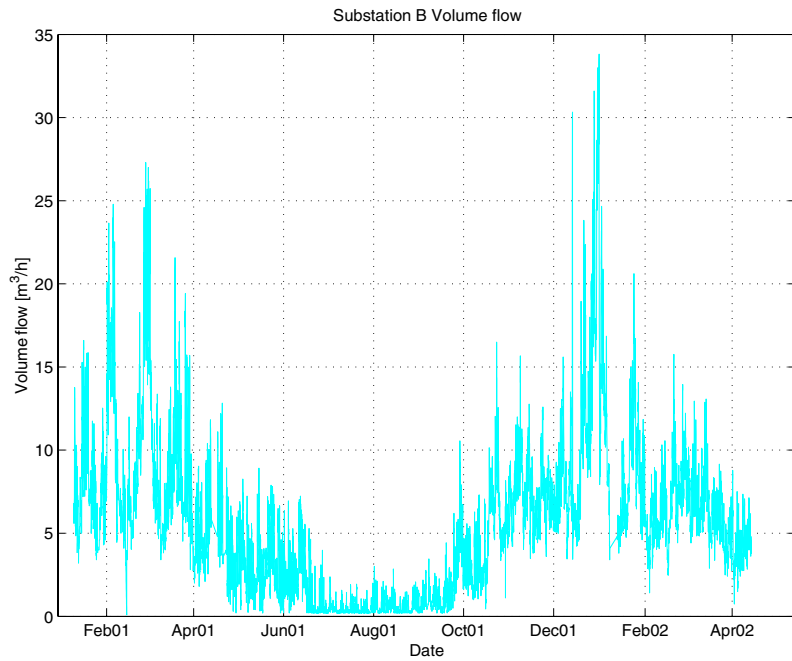*Figure 6-5 Connection station B: Heat load*

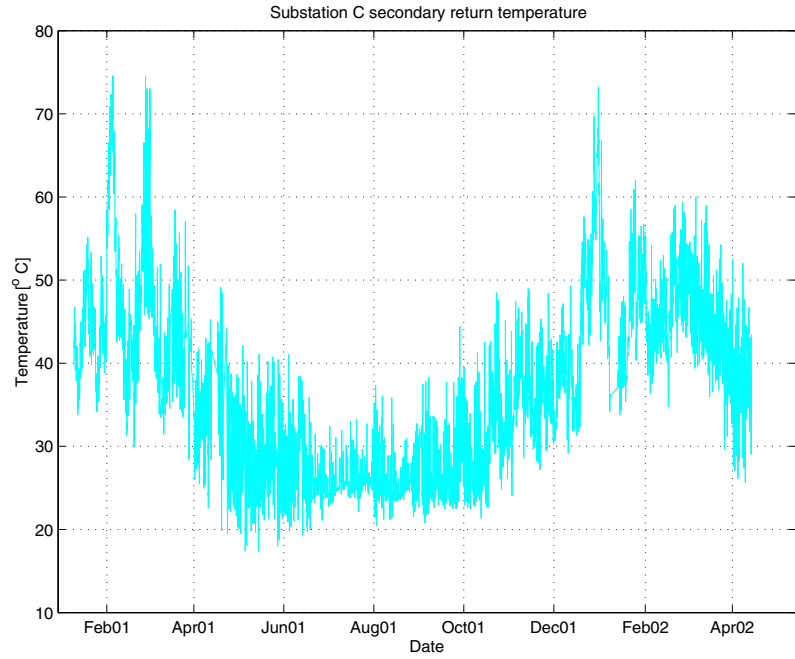*Figure 6-6 Connection station B: Volume flow rate*

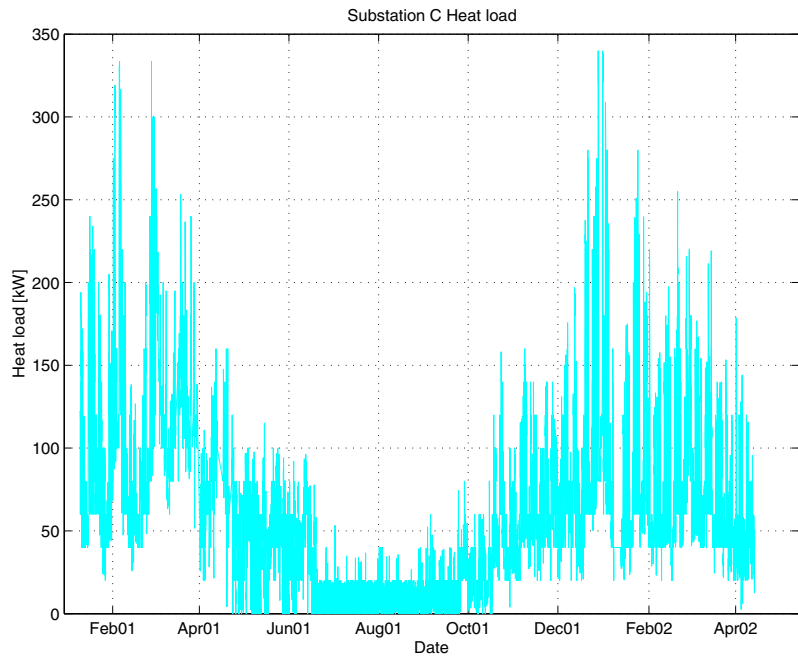*Figure 6-7 Connection station C: Secondary return temperature*

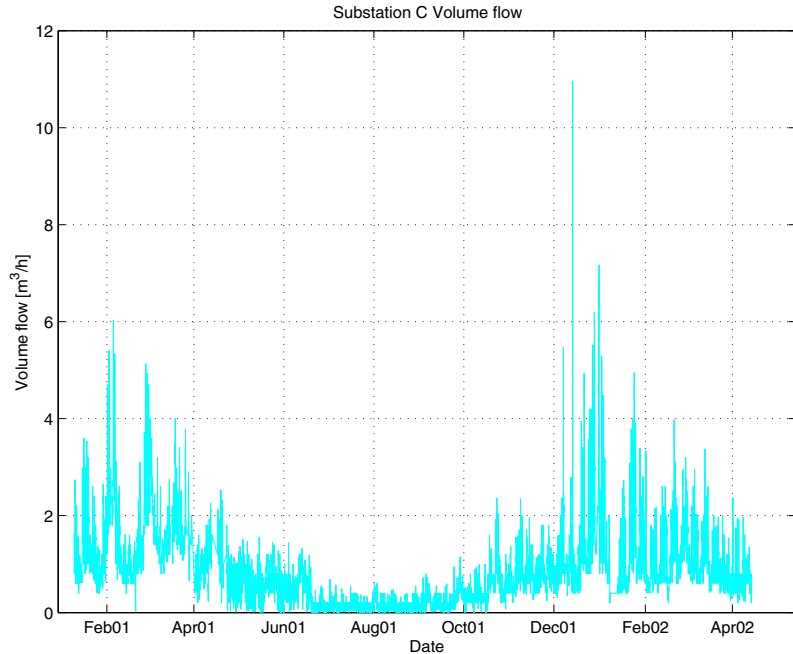*Figure 6-8 Connection station C: Heat load*

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Figure 6-9 Connection station C: Volume flow

6.3 Detection of inefficient consumer connection stations

It is well known that there is considerable economical potential in increasing the temperature difference in the primary district heating water supply. An increased primary temperature difference will result in increased efficiency of the heat production units, decrease the electricity consumption for distribution and decrease the heat loss from the network as a whole. In areas with limited heat transfer capacity an increase in primary temperature difference would probably be a very cost effective alternative compared to investment in new pipes. In a district heating network there will be a wide variation in the size of the consumer connection stations. As in many other distribution networks it is likely that a small amount of the consumer connection stations cover a large part of the annual energy sale. A common rule of thumb is the 80/20 division where 20% of the customers account for 80% of the energy consumed and sold.

There are several ways of estimating whether a consumer connection station is inefficient. A very common and simple method is the "over consumption" of water in a consumer connection station. By defining a target for the primary temperature difference the "over" or "under" consumption of primary water is given by [Walletun 1997]:

$$V_o = \frac{Q}{c_p \cdot \Delta T_p} - \frac{Q}{c_p \cdot \Delta T_{p\_d}} = V - \frac{Q}{c_p \cdot \Delta T_{p\_d}}$$

Where:
V_o is over consumption
V is measured volume flow for a known period of time
ΔT_{p_d} is target primary temperature difference.
c_p is the specific heat capacity of water

Since the method includes both energy and primary temperature difference, the result from sorting the consumer connection stations by amount of over consumption reveals the most important consumer connection stations for further investigation.

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The over consumption of water can be calculated over different time periods ranging from one year to one day (24 hours). The shortest measurement periods result in the largest variation in the final values. Over consumption on an hourly basis would result in useful information about which customers load the system most during periods of peak flow.

Several variations of the temperature efficiency have been adapted to consumer connection stations with different averaging and weighting factors [Gummerus 1989]:

$$\varepsilon_{tot} = \frac{\Delta T_p}{T_{p\_\sup ply} - T_{cold\_sevice\_water}}$$

In district heating systems with remote heat meter communication it is possible to use the over consumption of water directly by collecting the energy consumption and the volume flow for a given period. It is also possible to use temperature efficiency with an assumption of the temperature of the cold service water. The advantage of the over consumption of water method is that it also accounts for the size of the consumer connection station. Figures 6-10 to 6-12 show the amount of over consumption for connection stations A to C respectively.
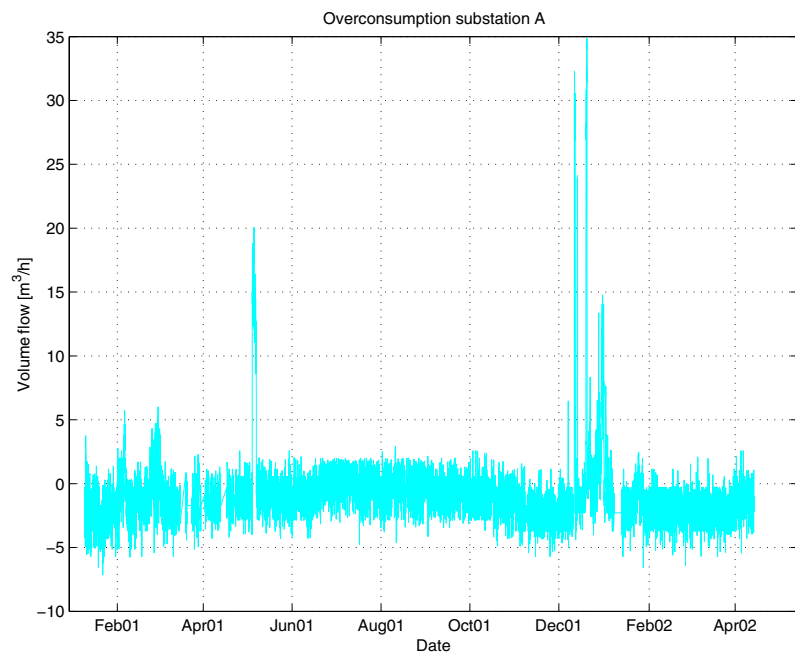

Figure 6-10 Over consumption: Connection station A
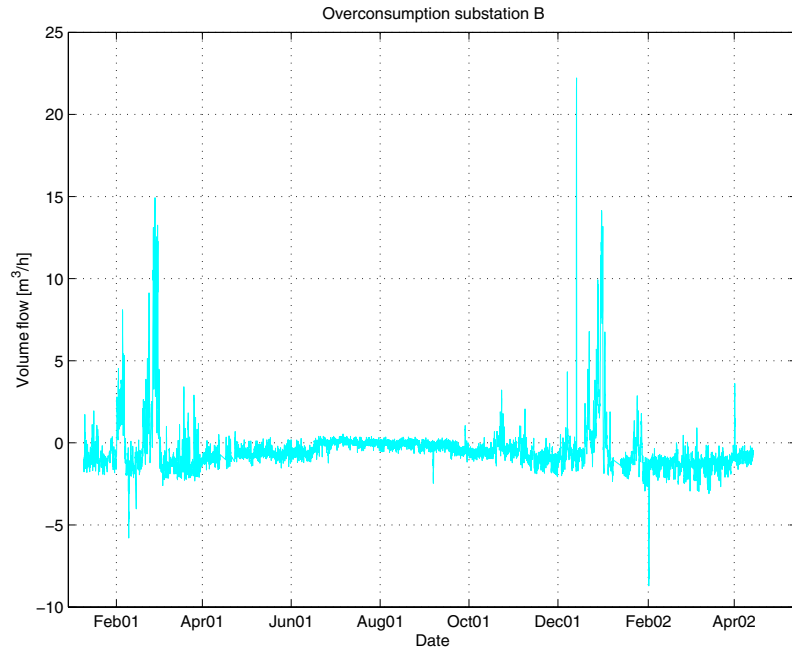
Figure 6-11 Over consumption: Connection station B
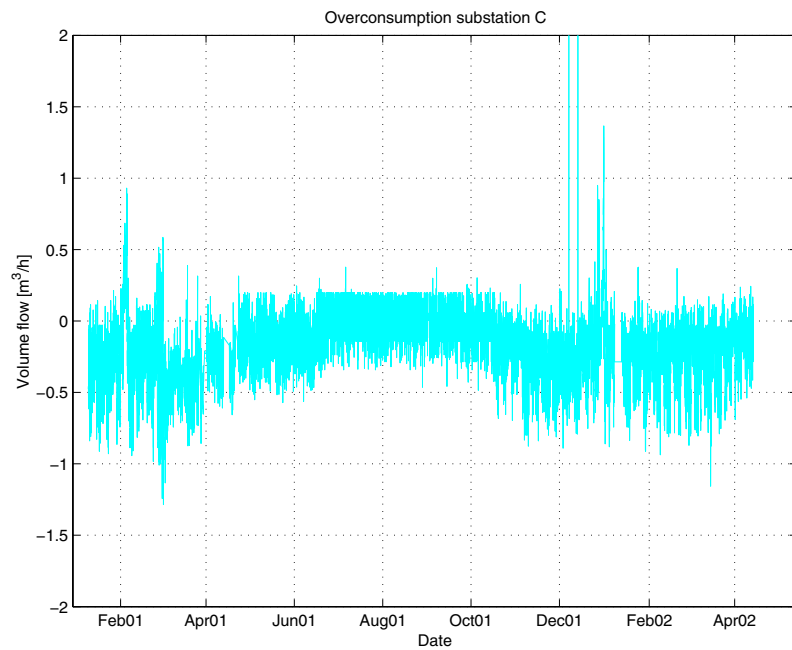
Figure 6-12 Over consumption: Connection station C

By remote reading the flow meter it is possible to collect the accumulated flow and energy and thereby calculate the over consumption for an arbitrary time period.

The accumulated over consumption with a target primary temperature difference during the measurement period are -10181, -4901 and $-1974 m^3$ for connection stations A to C respectively. The average cooling is generally better than the goal for cooling of primary water, i.e. 50 K.

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7 Adaptive control of secondary return temperature

Several reports conclude with the existence of an ideal secondary forward temperature which minimises the primary return temperature for district heating connection stations [Fredriksen 1995], [Volla 1996] and [Andersen 1997]. Common for these reports is that the suggested optimum secondary forward temperatures are calculated. An algorithm was developed and tested to try to obtain the same results in three actual consumer connection stations.

7.1 Algorithm

The algorithm shown in figure 7-1 is based on the method used in [Volla 1996]. In the simulations it is possible to keep all the input parameters constant and only vary the secondary forward temperature. If the room temperature is too low it is easy to increase the flow until the desired room temperature is achieved. In the simulations there are not any disturbances from solar gain, wind driven infiltration or variations in hot tap water usage.
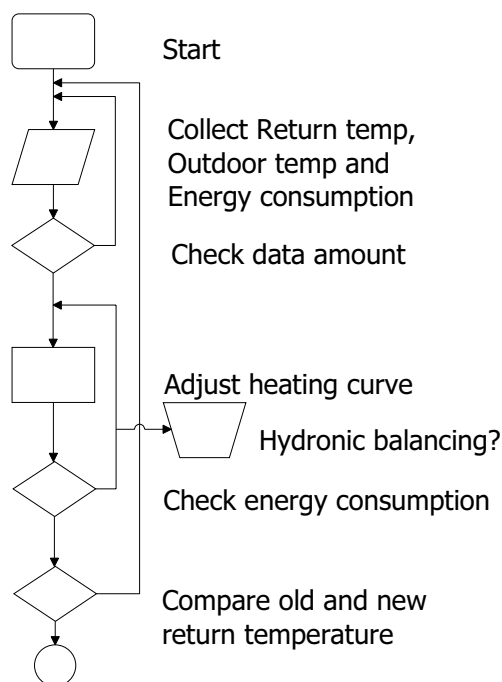

Start

Collect Return temp, Outdoor temp and Energy consumption

Check data amount

Adjust heating curve

Hydronic balancing?

Check energy consumption

Compare old and new return temperature

Figure 7-1 Algorithm used to find ideal secondary flow temperature

In the algorithm the first two steps try to establish an energy / temperature dependence for the building because in an actual connection station there are flow limitations and a too low secondary forward temperature can lead to too low room temperatures.

When the data necessary to establish an energy-temperature graph has been collected it is, in theory, possible to detect whether or not the building heat load is satisfied with the low secondary forward temperature.

Simultaneously the return temperature as a function of outdoor temperature is obtained for the actual secondary forward temperature. Then the secondary forward temperature is adjusted and new return temperatures are measured. The new return temperature is compared to the previous ones. For outdoor temperatures where the new curve gives lower primary return temperatures, the heating curve is adjusted further in the same direction. For outdoor temperatures where the old curve gives lower primary temperatures, the heating curve is adjusted in the opposite direction.

7.2 Test results

A series of measurement results of the secondary forward temperature plotted as a function of the outdoor temperature are shown in figures 7-2 to 7-4.
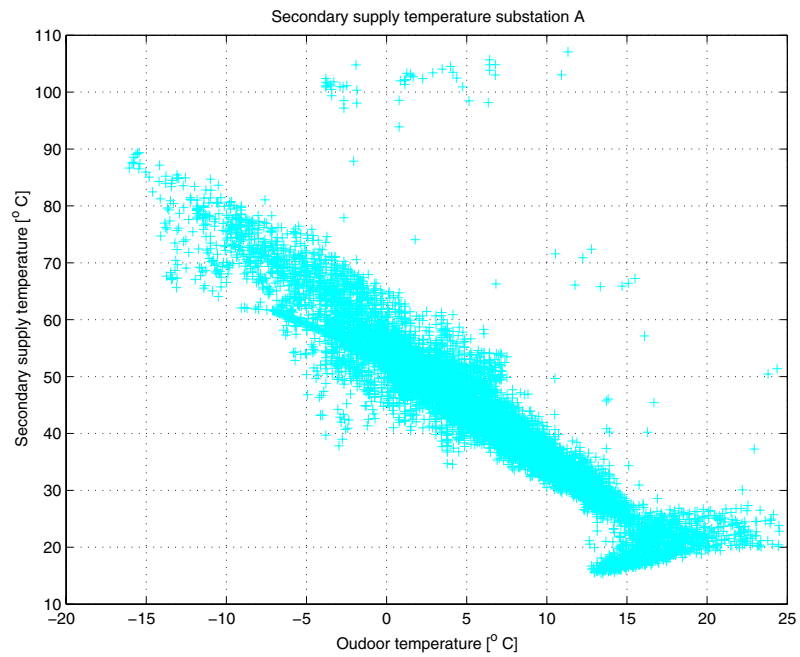

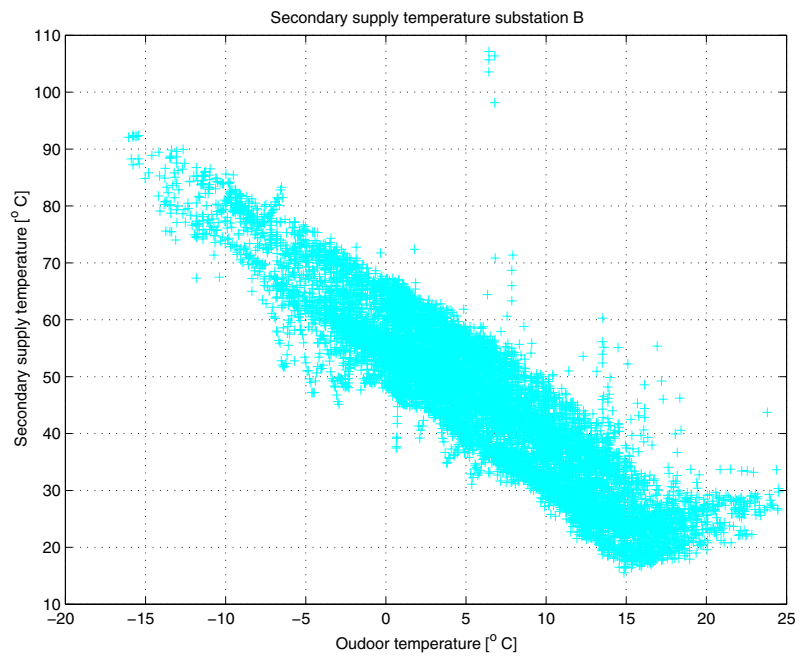*Figure 7-2 Connection station A: Secondary supply temperature*

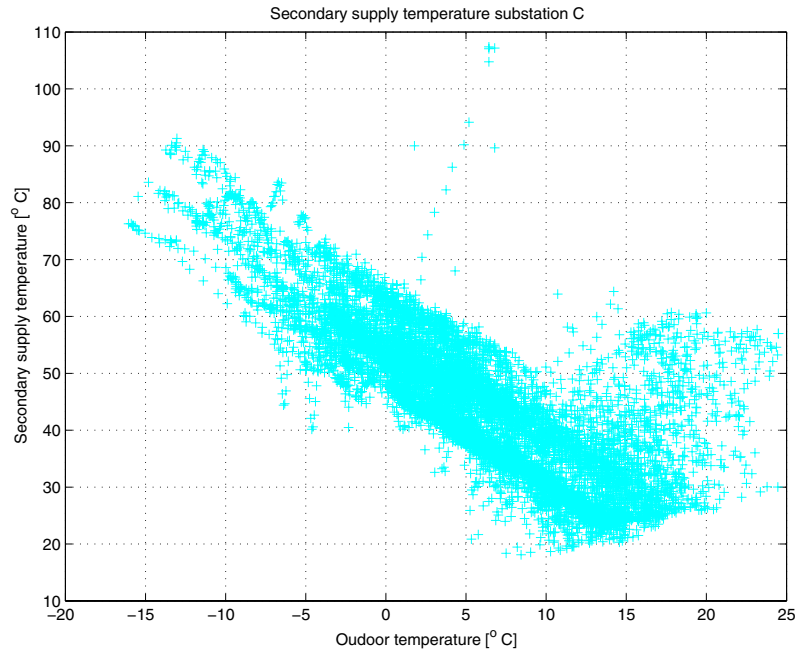*Figure 7-3 Connection station B: Secondary supply temperature*

Figure 7-4 Connection station C: Secondary supply temperature

7.3 Discussion and conclusion

The increase in supply temperature for an outdoor temperature above 15 °C is not correct. This increase is due to the fact that circulation pumps are stopped when the outdoor temperature is above 15 °C. The circulation pumps are started when the outdoor temperature is below 12 °C. This means that the measurement between 12 and 15 °C depends on the previous outdoor temperatures.

From the measurement results it is not possible to detect any relation between secondary supply temperature and primary return temperature or between secondary supply temperature and primary temperature difference.

Possible reasons for the incoherence between theory and practice can be many. The measurements have been carried out with an ordinary SCADA (Supervisory Control and Data Acquisition) system. This gives several possible measurement errors:

❍ The common outdoor temperature is not the same as the outdoor temperature actually used by the controller in each building.

❍ The sampling for the different variables is not done at the same time.

❍ The measurements of the temperatures are momentarily values while the energy and volume measurements are integrated over on hour.

The operating personnel recommended the existing sensor used for measuring the common outdoor temperature as it was known to be a reliable sensor. The sensor was known to not be influenced by solar radiation and give good agreement with metrological data. Since the objective was to obtain an energy-temperature dependence for the building, this sensor was chosen.

Figure 7-2 to 7-4 showed the secondary supply temperature as a function of the outdoor tempera-ture for two weeks in January. The measurements should give a straight line. Figure 7-5 to 7-7 show the consequence of the measurement problems for a short time period of time.
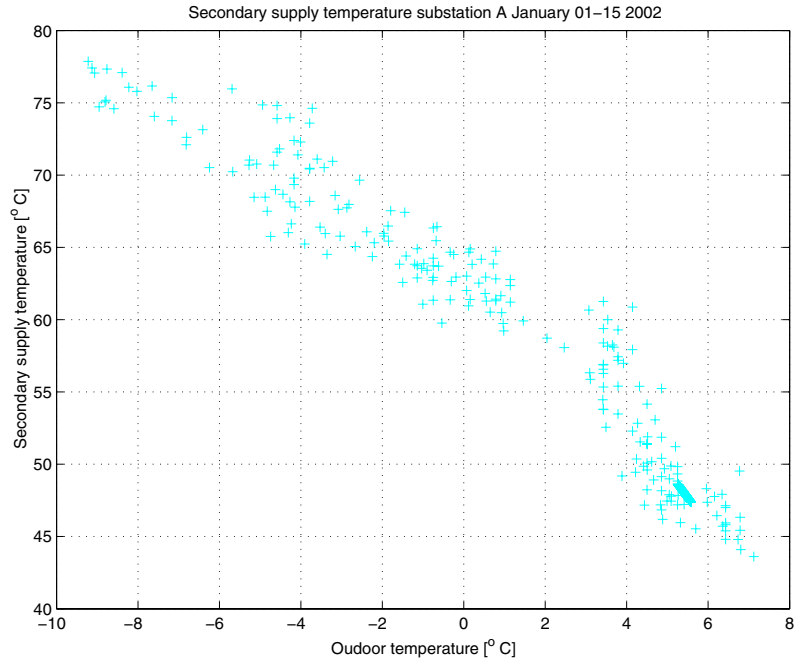
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Figure 7-5 Connection station A: Secondary supply temperature as a function of outdoor temperature
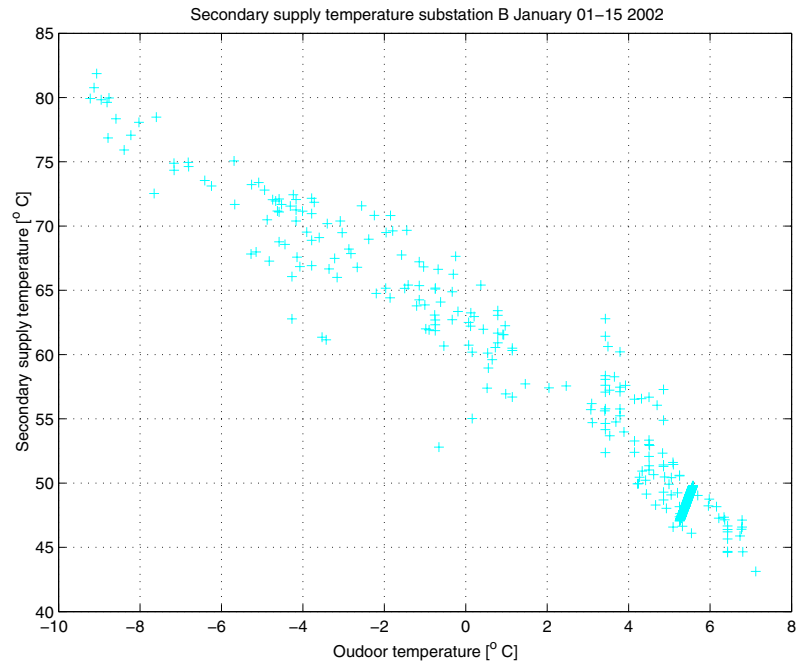

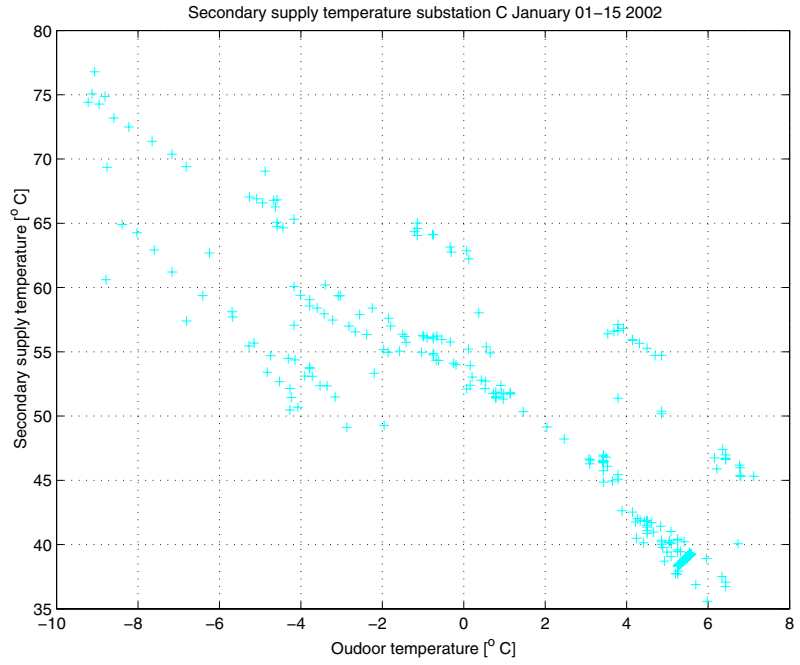*Figure 7-6 Connection station B: Secondary supply temperature as a function of outdoor temperature*

Figure 7-7 Connection station C: Secondary supply temperature as a function of outdoor temperature

8   Heat meter surveillance

Two-way communication with the heat meter is an obvious part of communicating with the connection station for billing purposes. It is also of interest to verify that the heat meter reading is operating correctly. The basic idea is to use a flow resistance installed in the connection station and to compare the measured differential pressure with the reading from the heat meter's flow meter. Both the district heating company and the consumer would be interested in achieving information about a faulty heat meter as soon as possible.

A long-term surveillance of the flow meter part of a heat meter has been conducted in a consumer connection station with an orifice plate flow meter in series with the heat meter. The measurement is described in detail in [Hoel 1998] and [Hoel 1999]. The conclusion from these reports is that the heat meter in the connection stations is unstable and the reading is generally too low. After these reports the flow meter in the connection station was replaced with a new flow meter in early 2000.

The orifice plate measurement was calibrated against the new installed flow meter at a flow above 8 l/s. This calibration deviates 1% from the calculated discharge coefficient according to [ISO 5167]. The calibration was done against the new installed flow meter instead of the ISO- method because the main interest is the long term behaviour of the flow meter used for energy calculations.

During two years of measurement the two flow meters have only small deviations from each other. For flow rates above 5 l/s the differential pressure measurements are of sufficient accuracy to be compared to flow meter used for the energy calculations.

An example for one day of measurement is given in figure 8-1.
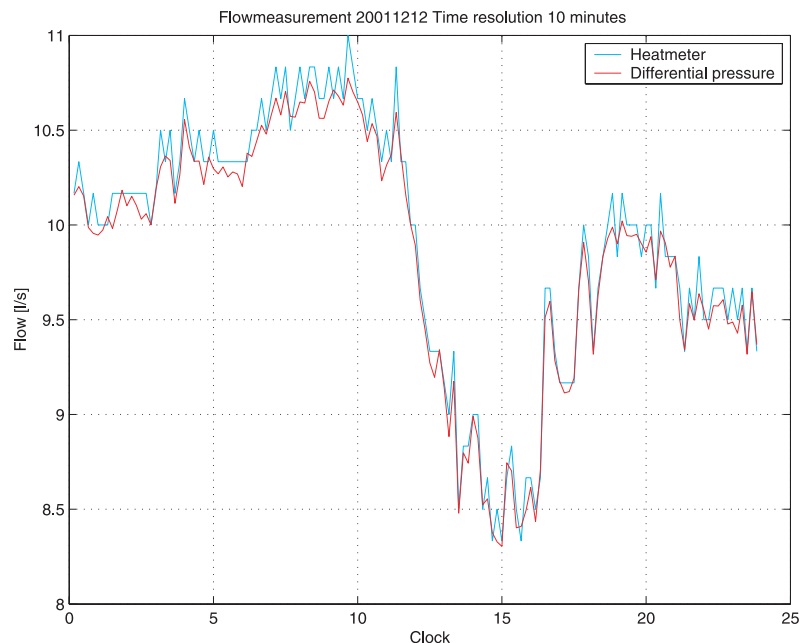
Figure 8-1 Example of flow measurement taken over one day

The average deviation for the day shown is 0.7 %. Generally the differential pressure measurements are slightly higher than the flow meter used for energy calculations at high flow. The maximum deviation for a 10-minute average is 2.5%. As seen from figure 8-1this deviation is partly due to the sampling error from the pulse measurement. The sampling rate of the measurement is 10 seconds. The conclusion from these measurements is that the flow meter used for energy calculation measures the flow according to the meter specifications.

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Appendix A   Communication media

A.1 Wired systems and their applications

Table A-1 gives a description of communication media for wired systems along with their advantages and disadvantages.
Table A-2a and A-2b illustrate some applications for wired systems for the telephone network and other networks respectively.

Wired system	Description	Advantages	Disadvantages
Twisted pair cables	Consists of two independently insulated wires twisted around one another. One wire carries the signal while the other wire is grounded and absorbs signal interference. Electrical and radio interference can be minimised further by positioning an extra shield around the cable, but at the cost of a lower transmission rate. There can be placed up to several thousand twisted pair cables on the public telephone net. The transmission rate for data and voice signals depends on the quality of the wire (the tighter the twisting, the higher the transmission rate & cost) and the transmission technology used: A traditional analogue telephone modem supports rates of 56 Kbps, whereas various DSL (Digital Subscriber Line) technologies offer transmission rates up to 100 Mbps.	Shielded (to a certain extent) against electromagnetic interference (EMI). Insulated against high voltage. No interference from nearby twisted pair cables. Its thin-wire properties make it easy to install.	Possible need for installation of new cables.
Coaxial cables	Consists of a central wire surrounded by insulation and then a grounded shield of braided wire. The shield minimises electrical and radio frequency interference. Data and voice signals can be transmitted digitally with a transmission rate of ca. 10 Mbps over distances of approx. 3-5 km.	Shielded (to a certain extent) against EMI. Cable uniformity prevents unwanted reflections and other disturbances.Supports high frequency and broadband transmission.Frequency multiplexing is possible (parallel data transmission over several channels).	Expensive to install. So far it has had limited application in remote meter reading.
Fibre-optic cables	A technology that uses glass (or plastic) threads (fibres) to transmit data. A fibre optic cable consists of a bundle of glass threads, each of which is isolated and shielded by a plastic coating and capable of transmitting messages modulated onto light waves. Data is transmitted digitally with a transmission bandwidth ca. 1,400 times larger than that for copper wire with transmission rates of 400-500 Mbps.Fibre-optic cables can either be single-mode, where light pulses only have one transmission line in one cable, or multi-mode, where a light pulse can have several transmission lines in one cable.	Large bandwidth. Much better protected against EMI than copper-based wires. Thinner and lighter than copper-based wires.	Difficult to join and split. More fragile than copper-based cables. Expensive to install and often needs an alternative power supply. Is gaining a wider application in telecommunications, but applications in remote meter reading are limited.
Powerline cables	Consists of several copper wires, each encapsulated in a shielding plastic coating. Data transmission can be both digital and analogue. Transmission rates are from 2,2 to 4,5 Mbps.	Due to the expansive use of the powerline net, the price of powerline cables and their installation is minimal. Its thin-wire properties make it easy to install.	Prone to EMI - especially if several meters are connected to the same transformer station.

Table A-1 Communication media for wired systems

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Wired system	Description	Advantages	Disadvantages
Telephone net	1. *PSTN (Public Switched Telephone Network)*: The international telephone system. Originally based on unshielded, twisted pair cables and analogue transmission.	Apart from the aforementioned advantages for twisted pair cables, PSTN is the most widely used telephone system.	Analogue data transmission means that digital data first must be transformed via a modem to an analogue signal. More prone to EMI, echoes and line spikes. Modem speeds are close to the theoretical maximum.
	2. *ISDN (Integrated Services Digital Network)*: Digital telecommunications system, which uses narrowband transmission (only one transmission channel at a time) to transmit voice, video and data over the existing twisted pair cables that PSTN employs. Can also transmit over fibre-optic cables. ISDN splits the telephone line up in three digital channels: 2 „B" channels for data transmission with each a transmission rate of 64 Kbps, and a „D" channel, which takes care of connection/ disconnection to the telephone net.	No need to modulate digital data to analogue and back again. Up to 3 times faster than existing modem systems. The most widespread communications system between computers, printers, modems and networks.	Maximum utilisation possibly requires fibre-optic cables. Comparatively expensive in installation and use.
	3. *BISDN (Broadband Integrated Services Digital Network)*: A further development of ISDN, which employs broadband transmission (several transmission channels at a time. Broadband transmission requires fibre-optic cables and has a transmission rate of max. 1.5 Mbps.	The same as for ISDN, though with greater data transmission rates.	Requires fibre-optic cables. Few, if any, applications in remote meter reading. Expensive in installation and use.
	4. *DSL (Digital Subscriber Line)*: a technology that allows more data to be sent over existing copper telephone lines. DSL works by sending digital pulses in the high-frequency area of telephone wires. Since these high frequencies are not used by normal voice communications, SDSL can operate simultaneously with voice connections over the same wires. Examples of this technology are: SDSL (Symmetric DSL) gives 144 Kbps - 6 Mbps. SDSL is called symmetric because it supports the same data rates for upstream and downstream traffic. ADSL (Asymmetric DSL) gives 1,5 - 9 Mbps (receiving data) & 16 - 640 Kbps (sending data). VDSL (Very High Speed DSL) can give 13 - 55 Mbps over a distance of 300 – 1500 m & ca. 100 Mbps for max. 100 m. supporting data rates up to 3 Mbps.	Much greater data transmission rates than for ISDN, BISDN & PSTN.	*General disadvantage with the telephone net:In some cases a meter can be inaccessible, where a telephone line either is impossible or unprofitable.*

Table A-2a Applications for wired systems relevant for remote meter reading (telephone network)

Wired system	Description	Advantages	Disadvantages
Powerline	For remote meter reading via powerline, a meter is connected to a powerline transceiver. At every transformer station a signal receiver/ detector is installed, which transmits the data on to the supply vendor's central computer. The English company RMS (Remote Metering Systems) has developed the system PLC (Power Line Communication) for remote reading of electricity meters. Data is traditionally transmitted analogue, but in the present years several companies have developed methods that with the help of modems enable digital transmission of data.	The widespread usage of electricity gives ample opportunity for connecting meters installed in less accessible places. The system is cheaper than a telemetry-based system. There is also the possibility of continuous data logging instead of the dial-up method employed in telemetry-based systems.	Problems with EMI, as well as connection to high-voltage lines are still considerable for powerline-based, reading systems. Two American companies, Nortel and Norweb, though, have announced the solution to many of these problems and can offer a method of data transmission via powerline with transmission rates from 500 Kbps to 1 Mbps. Future systems are expected to increase the transmission rate up to approx. 10 Mbps.
Cable TV and Ethernet	Coaxial cables are mainly used for Cable TV and Ethernet connections. In both cases a "tree branch" topology is employed for data transmission. For remote meter reading the meter is connected to a data encoder and a user interface to the cable network. Data logging at the supply vendor works the same way as for powerline transmission.	Large data transmission rate.	Most coaxial cable systems are originally intended for Cable TV and therefore not designed for two-way communication. Ownership of cable networks tends to change more often than that for telecommunication and electricity companies.

Table A-2b Applications for wired systems relevant for remote meter reading (other networks than the telephone network)

A.2 Wireless systems and their applications

Table A-3 gives a description of communication media for wireless systems along with advantages and disadvantages and table A-4 illustrates some applications for wireless systems.

Wired system	Description	Advantages	Disadvantages
Spread Spectrum	The most used method for wireless local area networks (LAN). Originally developed by the American military to avoid „jamming" and eavesdropping of signals. The signals are sent via the ISM (industrial, scientific and medicinal) frequency range: 902 MHz to 928 MHz and 2.4 GHz to 2.484 GHz. There are 2 types of spread spectrum: 1. *'Frequency hopping spread spectrum'*: Data is transmitted via an apparently random series of frequency ranges. Only a receiver that hops between the frequencies in synchronicity with the sender can receive all the data. 2. *'Direct sequence spread spectrum:* The most used method for wireless spread spectrum transmission. The data is assigned a code comprising of a row of data bits. Only a receiver that knows the code can receive the data. This means that several senders can work together without interference. The code comprises of at least 10 bits. Transmission power: less than 1 WMax. coverage: 33 m to 250 m, or up to 5000 m². Data transmission rate: up to 11 Mbps & 2 Mbps over 90-300m in the 2 GHz band for Direct Sequence & Frequency Hopping respectively.	Good data security. With the instalment of an antenna there is the possibility for communication between buildings. *General advantages of wireless data transmission:* Flexible installation for components that communicate wireless with a nearby LAN. Less costly in maintenance than a wired connection.	Comparatively low data transmission rate. *General disadvantages of wireless data transmission:* Can be very expensive to install. Also more susceptible to interference from light & electronics than cabled networks.
Narrow band microwave	Not a LAN technology as such, but rather a method used to connect other LANs between buildings. This requires sender/ receiver dish antennas at each end of the connection. The frequency band is kept as narrow as possible, while allowing data to be sent. Frequency range: 5,8 GHz. Transmission strength: 25 mWMax. coverage: up to 50m. Data transmission rate: 5-10 Mbps.	With the instalment of an antenna there is the possibility for communication between buildings.	Receiver and sender must be within range of vision. In USA (and presumably other countries) it is required to have a license for the employed frequency band, and when such a license is given the same frequency band must not be used by others inside a radius of approx. 10 km.
Infrared	Infrared WLANs transmit data via infrared signals, as do remote controls for TVs etc. Infrared transmission can either be point-to-point or "sun-to-moon", where the signal is reflected off a surface Frequency range: 3 x 10^{14} HzMax. coverage: 9 m to 30 mData transmission rate: 4-16 Mbps.	Very large bandwidth. No license is required for the infrared range. Cheap in installation and maintenance. As Infrared radiation does not penetrate walls, the data security is high and the same frequency band can be used in adjoining rooms without interference.	Sender and receiver must be within range of sight, as objects easily can block the signal. IR is exposed to EMI. The transmission power is limited to prevent eye damage. Obviously no possibility for communication between buildings.

Table A-3 Communication media for wireless systems

Wired system	Description	Advantages	Disadvantages
WDCT/ DECT	Worldwide Digital Cordless Telecommunications - a wireless telephone system connected to the wireborne telephone net. WDCT is an adaptation of DECT (Digital European Cordless Telephone) to suit the American market, operating in the 2,4 GHz band with transmission rates of approx. 2 Mbps. Voice data is first sent via radio signals to a telephone net connection and from there via the twisted pair, coaxial or fibre-optic cables used by the telephone net.	Communication is two-way. Possible to use the wireborne telephone net.	Data transmission via radio signals to the telephone net puts presumably a limit on the data transmission rate.
GSM	Global System for Mobile Communications. One of the leading cellular systems (where regions/ cities in a country are split up into cells). GSM is a *de facto* standard in Europe and Asia. GSM utilises TDMA (time division multiple access), which transmits data and voice signals digitally and allows 8 simultaneous calls on the same frequency. GSM operated originally only at 900MHz but later also at 1800MHz (also known as DCS1800), 1900MHz (also known as PCS1900) and 800MHz (E-GSM). GSM is considered a *2G* or second-generation wireless telecommunications technology, as opposed to UMTS (*3G*). A GSM network is composed of several functional entities, whose functions and interfaces are specified. The GSM network can be divided into three broad parts. The subscriber carries the Mobile Station. The Base Station Subsystem controls the radio link with the Mobile Station. The Network Subsystem, the main part of which is the Mobile services Switching Centre (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. The MSC also handles the mobility management operations. Not shown is the Operations and Maintenance Centre, which oversees the proper operation and set-up of the network. The Mobile Station and the Base Station Subsystem communicate across the UM-interface, also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile services Switching Centre across the A-interface. Data transmission speed: 9,6 Kbps.	No need for instalment of new cables. Digital, two-way data transmission.	Low data transmission rate in comparison with wired systems.
GPRS	General Packet Radio Service. GPRS is a new IP-based technology of packet data transmission in a mobile communications network. In theory, the GPRS was planned to offer an increase in data transmission speed of 30-40 Kbps (up to 115 Kbps under ideal conditions) - faster than the data transmission in the existing GSM mobile networks. The main features of the GPRS technology include: ❍ GPRS is a packet-based network of data transmission, where information is transmitted in short bursts of data over an IP-based network, using multiple time slots for data transfer as opposed to a normal single time slot. ❍ GPRS mobile phone is always connected to the network unlike GSM. ❍ As some cable-based network vendors offer their clients, a GPRS subscriber will be able to pay only for the data transmission and not for the time period of subscription to the network. GPRS is called a "2.5G" wireless technology: unlike UMTS it neither requires the construction of new transmission networks or fundamental reconstruction of the existing GSM network, but offers many features expected to appear in 3G technology.	*General advantages with data transmission via radio:Greater possibilities for connection to meters placed in inaccessible areas than for wireborne solutions.*	

Wired system	Description	Advantages	Disadvantages
UMTS	Universal Mobile Telecommunications System. Also referred to as *wide band code division multiple access* (W-CDMA). A further development of GSM towards the next generation (3G) of mobile telephones. Is expected to have a transmission rate of ca. 2 Mbps. Its applications will be in voice, data and picture/ video transmission in cellular telephones, TV and the Internet. It will operate in the 2 GHz frequency band, where it has been given an international bandwidth of 250 MHZ. With UTMS, the bandwidth of a mobile telephone will be variable. The system will use the following layer structure: 1. Mega cells: global coverage by satellites. 2. Macro cells: wide-area coverage (corresponding to present mobile systems) 3. Micro cells: coverage of densely populated areas, public institutions such as airports. 4. Pico cells: coverage of indoor uses e.g. buildings, offices and homes. The full implementation of UMTS is first expected to be in place in 2004-2005, due to the substantial investments necessary in cell station infrastructure. There are doubts from some telecommunication vendors as to whether customers will adopt UMTS, given the advanced functionality of the existing *2.5-G* systems.	Large data transmission rate. With a signal frequency of 2 GHz, the cells can be smaller, which allows a smaller transmission power.	Requires the establishing of new cell stations - cannot be applied to the existing GSM cell stations, as, for example, GPRS can.
ERMES	European Radio MEssage System. ERMES uses the same frequency band in all countries (169 MHz), and it is possible to transmit alphanumerical messages, i.e. alphabetical, numerical and diacritic symbols (such as å, ö, é etc.). *General paging: In 1998 the British government allocated the 183,5-184,5 MHz band for remote meter reading. However, this band is still used for broadcasting in much of Europe and therefore can not be used for meter reading on a pan-European basis.*	Several possibilities for data transmission. The same paging system for all EU countries.	Communication is only one-way. The technology may become redundant with the increasing use of SMS. ERMES has of 2002 not achieved acceptance as an industry standard within the European union (according to the British Radio communications Agency).
FLEX	A paging technology developed by Motorola, incorporating the FLEX protocol & the ReFLEX protocol, the latter enabling two-way paging. The FLEX Protocol enables paging speeds up to 6400 bps, achieved through multiplexing up to four data streams into one 6400 bps transmission. Each data stream, or phase, operates independently and pagers may decode multiple phases or a single phase. The FLEX Protocol supports up to five billion individual addresses and over 600,000 numeric pagers per channel (based on a call rate of 0.25 calls/hour at 100 percent airtime efficiency). FLEX is not committed to the 169 MHz band as ERMES is, but can "roam" over several frequency bands	The possibility for two-way paging enables district-heating systems to check that data has reached the receiver.	The technology may become redundant with the increasing use of SMS.

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SMS	<u>S</u>hort <u>M</u>essage <u>S</u>ervice (SMS) is a global wireless service that was conceived as part of the Global System for Mobile communications (GSM). SMS enables the transmission of alphanumeric messages up to 160 characters between mobile subscribers and external systems such as electronic mail, paging, and voice-mail systems with the same transmission speed as the GSM technology employed. SMS. The service makes use of a Short Message Service Centre, SMSC, which acts as a store-and-forward system for short messages. The wireless network provides the mechanisms required to find the destination station(s) and transports short messages between the SMSCs and wireless stations. In contrast to other existing text-message transmission services such as alphanumeric paging, the service elements are designed to provide guaranteed delivery of text messages to the destination. Additionally, SMS supports several input mechanisms that allow interconnection with different message sources and destinations. A distinguishing characteristic of the service is that an active mobile handset is able to receive or submit a short message at any time, independent of whether a voice or data call is in progress. SMS also guarantees delivery of the short message by the network. Temporary failures due to unavailable receiving stations are identified, and the short message is stored in the SMSC until the destination device becomes available. Initial applications of SMS focused on eliminating alphanumeric pagers by permitting two-way general-purpose messaging and notification services, primarily for voice mail. As technology and networks evolved, a variety of services have been introduced, including e-mail, fax, and paging integration, interactive banking, information services and integration with Internet-based applications. Wireless data applications include field-service applications such as automatic meter reading, remote sensing, and location-based services. Additionally, integration with the Internet spurred the development of Web-based messaging and other interactive applications such as instant messaging. SMS benefits include the following: ○ Guaranteed message delivery ○ Reliable, low-cost communication mechanism for concise information ○ Delivery of messages to multiple subscribers at a time ○ Ability to receive diverse information ○ E-mail generation ○ Creation of user groups ○ Integration with other data and Internet-based applications The benefits of SMS to the service provider are as follows: ○ An alternative to alphanumeric paging services. May replace or complement an existing paging offer ○ Ability to enable wireless data access for corporate users ○ Provision of key administrative services such as advice of charge, over-the-air downloading, and over-the-air service provisioning The application of SMS in Denmark has been a great success: from the first half-year in 2000 to the first half-year in 2001 the number of SMS messages sent has risen from 287 million to 619 million. This tendency has also been observed in other European countries. SMS is also being incorporated into the *2.5G* technologies such as GPRS.
WAP	<u>W</u>ireless <u>A</u>pplication <u>P</u>rotocol: A specification that allows users to access information instantly via handheld, wireless devices such as mobile phones, pagers, two-way radios, smartphones and communicators. WAP supports most wireless networks and is supported by all operating systems. WAPs that use displays and access the Internet run what are called micro-browsers - browsers with small file sizes that can accommodate the low memory constraints of handheld devices and the low-bandwidth constraints of a wireless-handheld network. Although WAP supports HTML and XML, the WML language (an XML application) is specifically devised for small screens and one-hand navigation without a keyboard. WML is scalable from two-line text displays up through graphic screens found on items such as smart phones and communicators. It is similar to JavaScript but makes minimal demands on memory and CPU power because it does not contain many of the unnecessary functions found in other scripting languages. Because WAP is fairly new, it is not a formal standard yet. It is an initiative that was started by Unwired Planet, Motorola, Nokia, and Ericsson. WAP has until now only had limited success, which can be due to several factors: a low data transmission rate of 14 Kbps or less (some vendors promise though speeds up to 170 Kbps, when WAP is fully incorporated in GPRS), its cost & the fact that only a selected number of web sites are configured to allow access by WAP.

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Bluetooth	Bluetooth is a new standard launched in May 1998, which utilises a short-range radio link to exchange data, enabling wireless connectivity between printers, mobile phones, hand-free headsets, LCD projectors, modems, wireless LAN devices, notebooks, desktop PCs, PDAs, as well as other devices. Three classes of transmission output are available: 1mW capable of transmissions covering distances with a radius of about 10m, 2.5mW for transmissions up to about 30m, and 100mW for transmissions extending about 100m. The maximum data transmission speed is 1Mbps. One terminal can simultaneously communicate with a maximum of seven external units. It aims to replace the IrDA specification of InfraRed in mobile and computing devices. There are five companies that have contributed to the development of Bluetooth: Ericsson, Toshiba, IBM, Intel and Nokia. The Bluetooth System has the following characteristics: ❍ Operates in the globally available 2.4 GHz Industrial-Scientific-Medical (ISM) band. ❍ 10m to 100m range ❍ Uses frequency hopping spread spectrum, which divides the frequency band into a number of hop channels. ❍ Supports up to 8 devices in a Pico cell (two or more Bluetooth units sharing a channel). ❍ Built-in security. ❍ Non line-of-sight transmission through walls and briefcases. ❍ Omni-directional. ❍ Supports both synchronous and asynchronous services; easy integration of TCP/IP for networking. ❍ Regulated by governments worldwide. The adoption of the Bluetooth technology has been somewhat delayed, due to uncertainties of its compatibility with other wireless systems.
HomeRF	HomeRF is similar to Bluetooth in that it operates in the same 2.4GHz spectrum, but HomeRF has a transmission rate of 1.6Mbps per second. Future HomeRF transmission rate will be up to 10Mbps sec. This improved HomeRF will make it more suitable for transmitting music, audio, video and other high data applications. The range of HomeRF is about 160 feet. HomeRF can not only transmit data but also up to 4 voice phones. The general idea of the HomeRF system is that there is a main control device communicating with the other HomeRF devices. The main HomeRF control device can then wake the other devices when needed from their idle state and make them ready for use. This HomeRF idea makes it suited for such devices as printers, modems etc. Because HomeRF has a reasonable range it could cause interference with other nearby HomeRF networks or devices. HomeRF therefore incorporates a learning feature so that only your HomeRF setup & devices communicate with each other & not any other HomeRF networks nearby. HomeRF security uses a 24-bit network IP that is specific for each HomeRF network and data is sent with 56-bit encryption. Future encryption is expected to be 128-bit encryption. Another security feature is that HomeRF devices constantly switch the frequency they communicate with, this HomeRF feature will make any denial of service attacks very difficult.

Table A-4 Applications for wireless systems relevant for remote meter reading