COOL DH
COOL DISTRICT HEATING

Cool ways of using low grade Heat Sources from Cooling and Surplus Heat for heating of Energy Efficient Buildings with new Low Temperature District Heating Solutions.

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Authors: Per-Olof Johansson Kallioniemi, Kerstin Sernhed, Janusz Wollerstrand - Lund University, Markus Falkvall, Klara Ottosson, and Arnela Kursumovic – Kraftringen AB.

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Dissemination level		
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Scope of deliverable

This report is about "individual metering concepts" - that is new ways of using data gathered for billing. The aim of the report is to give insight and ideas for new use of consumption data gathered from the customer district heating substations. The report gives a general overview of methods that are currently used for measurement data analysis and gives examples of projects that create new applications of measurement data use in order to develop and improve the conditions for efficient operation and good operational planning.

Furthermore, some digressions are made in a couple of different fields that are important for the development of district heating systems.

Context of deliverable

The report provides an overview of regulations on district heating metering and billing in Sweden and Denmark and an overview on applications where customer's meter readings can be used for energy efficiency improvements. The report intends to provide insight into important factors to consider when choosing meter and communication systems for district heating.

Perspective of deliverable

The LTDH-system is monitored by direct connection to the heat meters at all the consumers. The data from the heat meters can be used as a basis for describing, predicting and analysing the system's performance for better control of production and operation, for better conditions for troubleshooting and maintenance of the grid and the customer installations as well as for better customer service. Knowledge of which requirements should be set on meters and measuring systems is of interest to the district heating industry.

Involved partners

Prepared: Lund University (Department of Energy Sciences) and Kraftringen AB was responsible for compiling and authoring this report.

Reviewed: COWI A/S, Reto M. Hummelshøj, 17 April 2019

Approved: COWI A/S, Reto M. Hummelshøj, 18 April 2019

Summary

In a low temperature district heating (LTDH) system the importance of well performing network and customer installations are essential due to reduced operating margins. The use of low-value waste heat in the production sets limitations on the supply temperature. New piping materials sets limitations on the supply temperature and the pressure level. All in all, this means an increased focus on ensuring that DH installations are well performing.

This report is about 'individual metering concepts'. The LTDH-system is monitored by direct connection to the heat meters at all the consumers. The data from the heat meters can be used as a basis for describing, predicting and analysing the system's performance for better control of production and operation, for better conditions for troubleshooting and maintenance of the grid and the customer installations as well as for better customer service.

The aim of this report is to:

- give an overview over the current regulations for metering and billing of heat in Sweden and Denmark
- give an overview of desirable functionalities for DH meters and metering systems
- to provide input to applications that can be developed with the help of meter readings and which can be useful for the district heating industry
- describe how DH meter readings can be used for condition monitoring of service pipes and develop a method for this

Regulations for metering and billing of DH follows EU regulations which says that all DH customers must be charged according to actual consumption. The overview of the current regulations for metering and billing in Denmark and Sweden shows that the two neighbouring countries have somewhat different approach to the individual metering concept. In Denmark there is a long tradition of individual metering in multifamily buildings and the tenants heat consumption is measured. In Sweden there is no such tradition and the individual metering concept generally is not in focus. Instead, the property owner is the customer. Denmark follows the Energy Efficiency Directive from 2012 (supplemented 2018) that requires individual metering and charging. The Swedish regulations on metering and billing are based on the exception in the EU regulation concerning individual metering and charging saying that individual metering must be economically justifiable. The Swedish National Board of Housing has shown that implementation of the EU regulations is not economically justifiable for the Swedish case - neither for existing buildings or in new buildings.

There is a general attitude that increased frequency and higher resolution of meter readings automatically results in increased possibilities for new and improved analyses of customer performance. At present there are several researchers and research groups that are using meter readings from DH customers and machine learning with the aim to improve the energy performance of both the DH customer installations as well as the DH network and production operation. From ongoing projects four areas for applications have been identified: Fault detection, Load prediction, Production planning and Operational optimization. For these applications hourly meter readings are sufficient, at least in combination with historical data and weather conditions. For improved fault detection algorithms and moving towards fault diagnosis it would be beneficial to access secondary meter readings such as temperatures in the secondary side heating- and domestic hot water system as well as indoor temperatures. When moving on towards fault diagnosis, the frequency may also be in focus. A temporary shift to meter readings with higher frequency may be necessary for diagnosis. All in all, it might not be the frequency of the meter readings that should be increased, it might be more beneficial to include more meter parameters from the customer side of the heat exchanger. By integration of more meter parameters, the focus may shift from a matter of frequency to the broad concept of Internet of things (IoT).

One scope within this project was to evaluate the feasibility for usage of meter readings from customer installations to detect increased heat losses in service pipes due to moisture. A theoretical study was carried out, but it did not turn into a success. Results showed that even though the heat losses in the service pipe increases due to moisture content, the impact on the measured parameters, that is temperature and flow, are low and would be hard to detect. A higher resolution or increased frequency of meter readings would not improve the feasibility to use meter readings for monitoring increased heat losses in service pipes since if feasible, it would require stable heat load at the customer installation and stable and known temperature conditions in the DH network.

Through studies performed within this work and by other researchers it is clear that DH utilities, both in Denmark and Sweden, has a desire to improve customer performance and to reduce the DH return temperature. A key factor for success within this field is good customer relations and access to the customer's DH substation. This may be a driving force for DH-utilities to offer service agreement and ICT-platforms for greater customer engagement. Customers seems to be more willing to take actions to improve their installations if they understand why it is important.

Recommendations:

The following recommendations are given based on the overall picture provided by the report's different compilations and studies:

- The meter should be able to measure the energy for every hour and be able to convert to measure with higher frequencies (minutes). Some types of measurement data analyses may require a higher resolution than hourly measurement, which is why the possibility of higher resolution should be provided, without that being a default setting.
- It should be possible to remotely upgrading the meters and to remotely change the meter frequency. This will provide that new functionalities can be introduced in a cost-efficient way and that expensive field visits can be avoided.
- Access to secondary meter readings. The following measurements were seen as the most important: Indoor temperatures, secondary temperatures measured on branches for the heating system in the building, and measurement on the district heating differential pressure. Measuring these parameters would be beneficial for developing algorithms for fault detection and for improving system performance for the total district heating system, as well as for as being able to guarantee the quality of energy supplies at the customer substations.
- There should be a digital interface that the end customers can use to access their energy consumption locally. The communication solution should also support a future standard for communication with devices in the home. In order to be of real use for the customers, this should be delivered with some kind of analysis tools that can help the customers relate their consumption or data to reference data (for example historical data, norms or set point values) and that can provide the customer with extended analysis that make sense to the customer.

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List of abbreviations

AMR – Automated meter readings

DH – District heating

DHW – Domestic Hot Water

DSO – Network operator

EED - Energy Efficiency Directive

EN 1434 – Metering standard within EU

HWC – Hot Water Circulation

ICT – Information and Communication Technology

IMC – Individual metering and charging

IoT – Internet of Things

JRC – Joint Research Centre (of the EC)

LoRaWAN – Long Range Wide Area Networks Protocol

LON – Local Operating Network (protocol for transmitting information from the meter's communication port)

Mbus – Meter bus (a European standard for the remote reading of consumption meters - a protocol for transmitting information from the meter's communication port)

ML – Machine Learning

Modbus – (a serial communications protocol originally published by Modicon, now Schneider Electric) - a protocol for transmitting information from the meter's communication port)

PLC – Power line communication

P2P – Point-to-point (data communications through cellular grid)

SH – Space heating

SIOX – Serial Input /Output eXchange (asynchronous serial communication bus - protocol for transmitting information from the meter's communication port)

SWEDAC – Swedish Board for Technical Accreditation

1 Introduction

Cool District Heating is a project anchored in two demonstrations of low temperature district heating systems in the cities of Lund in Sweden and Høje-Taastrup in Denmark. Both cities have high ambitions on climate and smart-city policies and want to implement smart system solutions for their next generation district heating.

This report is about 'individual metering concepts'. The low temperature district heating (LTDH) system is monitored by direct connection to the heat meters at all the consumers. The data from the heat meters can be used as a basis for describing, predicting and analysing the system's performance for better control of production and operation, for better conditions for troubleshooting and maintenance of the grid and the customer installations as well as for better customer service.

Different conditions in the low-temperature district heating network lead to reduced operating margins. The possibilities to temporarily raise the supply temperature in order to cope with peak loads or bottlenecks is limited by the use of low-value waste heat in the production. At the same time, is the possibilities for increasing the flow rate in the district heating water limited by the choice of material in the district heating pipes, where the use of plastic pipes may lower the installation costs, but has the disadvantage that plastic material cannot withstand the same pressure as conventional district heating pipes of steel. This limits how much the pump pressure can be increased in the pipes. Thus, the need for smart control, optimization and troubleshooting is even greater in a low-temperature district heating system compared to a conventional.

The aims and methods of this report are:

1. to describe the current regulations for metering and billing of heat in Sweden and Denmark. This has been done by studying legal requirements.
2. to describe desirable functionalities for meters and measuring systems, by studying information from measurement companies, industry associations and specialists. An outlook has also been made to the electricity industry, which is judged to be ahead of the district heating industry when it comes to automated meter reading systems.
3. to give input to what applications data from meter readings can be used for in the district heating business. This has been done by analysing what applications have been used in different research projects about data analysis using meter readings for electricity and for district heating. One application of certain interest for the LTHD grid is fault handling of erroneous customer installations. Therefore, an emphasis has been made to describe the importance of good cooling in the district heating networks and an investigation has been carried out on how Swedish and Danish district heating companies work today with the issue of attaining good cooling in the district heating grids. This has been investigated through interview studies and questionnaires.
4. The use of DH meter readings for condition monitoring of insulation status in the DH service pipes is a scope mentioned in the COOL DH application. Typically, the service pipes lack system for leakage detection and therefore there is a lack of traditional methods for automated status detection of service pipes. A method for detecting leaks in supply service pipes analysing customers meter readings has been evaluated in a theoretical study based on a backwards theoretical reasoning on how much damage there must be in the insulation of a service pipe in order to be detected as an anomaly in measurement data.

With input from the report's various parts and sub-studies, conclusions have been made and recommendations have been given regarding individual metering concepts.

2 Automated meter reader systems for heat

The motive for measuring flow and temperature at the customer district heating substation is to calculate the energy used by the customer and hence the metering contributes to an objective and fair treatment of the customer. Historically, the collection of measurement data for charging purposes was carried out by employees in the energy companies actively visiting the meter units at the customers, once a year, to register measured values regarding the customers' consumption. In some countries the billing was even based on estimated values. Today the metering is enforced by law in most modern industrial countries (Frederiksen & Werner, 2013).

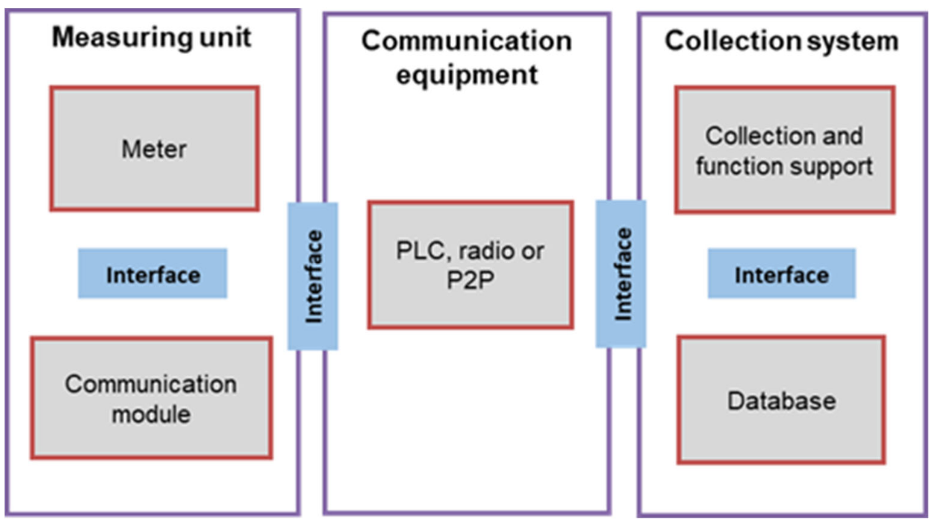

Figure 1. Components of the metering system. Modified after SWECO, in Swedish Energy Markets Inspectorate, (2015).

Figure 1 describes the components and setup of a metering system. First of all, there is the measuring unit which consists of a meter and a communication module for collection of measurement values. The communication can occur in three different ways, the most common today are Power line communication (PLC), which is communication through the electric grid, communication over radio, or P2P which is communication through the cellular grid (GPRS or GSM communication. New possibilities are also communication via the city fiber optics network (National Encyclopedia 2018) or via LoRa network, also called LoRaWAN, which is a communication interface where sensors on the relay node are used to send signals to the terminal via a local network (Ambiductor 2018). Fiber connection has high transmission capacity and speed. It is also insensitive to disturbances that may arise from electric or magnetic fields but, on the other hand, has weaknesses since this communication interface requires constant connection to the city network. Communicating through LoRa networks requires less energy and can often be done wirelessly, with only battery as an energy source, but the technology does not cover the response times and coverage rates that are desirable. The LoRa system can handle bidirectional communication but since the responder in most applications is only open during certain time intervals, it cannot cope with constant communication (Ambiductor, 2018).

The collection system has two functions: continuous collection of values and regulation of different functions. It is often connected to a database of measurement values and billing information (Swedish Energy Markets Inspectorate, 2015).In order to be able to read information from the meter, there must be an interface from the equipment that provides the opportunity for this. Different suppliers have solved this in different ways, either via internal ports or terminals, or via extra add-on or modules. According to Swede Energy's report on technical regulations for heat meters (Energiföretagen, 2019), the most common protocols for transmitting information from the meter's communication port are Mbus, LON, SIOX and Modbus.

2.1 Heat meters

A heat meter basically consists of a flow meter, a temperature sensor pair and an integrator. The flow meter works in the same way as a water meter, but is designed for a continuous water flow. The temperature sensor pair measures the temperature difference between the water flow in the inlet and outlet of the connection. The integration unit receives the measured value from the flow meter and the temperature sensors and integrates them to a value of used heat energy in kWh (Svenska Leverantörsföreningen för Individuell Mätning och Debitering, without year). Heat meters are powered by electricity, either from the public grid or with batteries that have a typical life of 10 years. Within the flow rate measurement technology there are a large range of types of flow meter. The most commonly used types are vane wheel/impeller, turbine/Woltman wheel, electromagnetic induction and transit-time ultrasonic (Frederiksen & Werner, 2013). Today ultrasonic flow meter is most commonly used.

In Sweden, heat measurement must be type-approved, which means that components included are reviewed and meet the regulatory authority SWEDAC's requirements (Swedish Energy Markets Inspectorate, 2010).

2.2 Automated meter readings

Automated readings from metering instruments can either be fully remote or involve personnel passing by customer premises to take readings from the outside (Frederiksen & Werner, 2013). Today's technologies for automated meter readings from district heating systems are based on either radio communication, communication over the electricity network (Power Line Communication, or PLC short), or mobile communication through a point-to-point solution (P2P).

2.3 Regulations for meters and metering

Within EU there is a European metering standard EN 1434, which provides detailed specifications for heat metering. It has been implemented in national standards and recommendations issued by authorities and by district heating associations (Frederiksen & Werner, 2013).

From the changes in the Energy Efficiency Directive that came in 2018 (EU 2018/2012) it can be derived that new heat meters installed after the 25th of October 2020 must be remote readable and existing meters that are not remote readable must be replaced or upgraded so that they can be read remotely by 1st of January 2027.

EWII, Grøn Energi and Transistion (2019) made a survey with 114 district heating companies in Denmark about heat meters and data collection systems for metering and billing of district heating consumption. The survey showed that all meters acquired today in Denmark (at least among the responding district heating companies) can measure energy delivery with high frequency, and deliver remote readings. The requirement from the Energy Efficiency Directive for new meters is therefore already fulfilled today for the meter itself. The directive's requirements on remote readability however also include the data collection infrastructure, why the companies using drive-by solutions or manual reading will probably have to invest in this in order to fulfil the requirements. The study showed that for 55% of the district heating companies, there were no need for upgrading their meters or communication systems to comply with the directive, 38% needed to do smaller upgrades and only 7% of the companies needed to do major upgrades.

Since 1st of January, 2015, district heating customers in Sweden are entitled to monthly reading of their consumption, which has led to the fact that remote heat meters now are standard in district heating sales. Today's modern district heating meters provide the opportunity for high-resolution measurement values in close real-time (Bergmark& Näslund, 2019).

In Sweden, the regulations for meters and metering deal with the requirements for the heat meters themselves (STAFS 2016: 1), requirements for new meters that are put into operation (STAF 2016: 5) and requirements for heat suppliers to control the meters' function (STFS 2007: 2). SWEDAC is an accreditation body and is governed by regulations on accreditation (STAFS 2015: 8) and control body (STAFS 2011: 18). Swede Energy (which is the industrial organization for electricity and district heating utilities in Sweden) have technical industry requirements for thermal energy meters, which supplement the requirements set by the authority. These are reported in technical regulation F: 104 - Thermal meters - Technical industry requirements and advice on meter management (Energiföretagen Sverige, 2019).

The Energy Markets Inspectorate's regulations and general advice (EIFS 2014: 2) contains rules for measuring, reporting and billing the delivered heat. The following rules apply for the Swedish case:

- The customer must be charged according to actual consumption (according to EIFS 2014: 2), which means the actual amount of energy withdrawn by the customer.
- In accordance with the law, all charge-based parameters should be based on actual measured values from the thermal energy meter.
- The energy supplier has a great responsibility for measuring the correct customer withdrawal and also for being able to present this and the other measured values for the different parameters that form the basis of price models that are used to charge the customers.
- The lowest time resolution, according to the law, is daily values for the energy consumption and other load-based measurement values. If a price component is used that need a higher resolution time than day based metering, these measured values should also be reported to the customer.
- In the event of an error or lack of measured values, the energy supplier has a limited possibility to make a calculation or estimation, according to the regulations. Calculations may be carried out in exceptional cases, by using accepted methods and statistics secured for the customer group.
- The heat supplier shall, without special expense for the heating customer, provide data on consumption per day, week, month and year for a period that includes at least the last two years or the current delivery contract term, if this is shorter. Information on historical use shall be made available quarterly if the customer so requests, and otherwise at least twice a year. This applies to all billing values.

2.4 Regulations for individual metering and charging

In 2012 the Energy Efficiency Directive (2012/27/EU) was introduced in the EU member states. Article 9 of the directive, requires member states to ensure that building contractors and property owners install individual meters so that each apartment's energy use for heating, cooling and domestic hot water can be measured. The aim of the article is to raise the awareness of energy use in the households and to give the households means to influence their costs.

The tradition of individual metering for heat and domestic hot water is different in Denmark and Sweden. Denmark has a long tradition of individual metering whereas the introduction of individual metering in Sweden is sparse.

Sweden has implemented the article 9 through the Act on energy measurement in buildings (Lagen om energimätning i byggnader, 2014:267). This act includes requirements on building contractors and owners to make it possible to measure heating, cooling and domestic hot water individually in each apartment. However, the requirement only applies if the measure is cost-effective. Boverket (the Swedish National Board of Housing, Building and Planning) was commissioned by the Swedish government to investigate whether individual metering and charging can be seen as a cost-effective investment or not, and to specify in which cases metering systems for heating, cooling and domestic hot water should be installed in buildings (Boverket, 2015). The commission (N2014/1317/E) was divided in two parts. The first part concerned new construction and reconstruction projects. For this part Boverket recommended not making individual metering and charging of heating, domestic hot water or cooling a requirement. The reason for this was that the results from the investigation showed the investments in individual metering not to be cost efficient. Similar conclusions were drawn for the second part of the investigation that concerned existing buildings. Here, the boards calculations showed that an investment in individual metering and charging using heat cost allocators or temperature metering was generally not cost-effective and the investments appeared risky. All in all, the recommendation from the Swedish National Board of Housing, Building and Planning was that individual metering of heating, cooling or domestic hot water is not required in any existing building's case. For that reason, the board is not making any proposals for regulatory provisions.

Denmark has long had a high proportion of users of individual metering and charging (IMC) as well as legislation on compulsory measurement and debiting at individual level. In 1997, a mandatory introduction of individual measurement and charging was enacted. The introduction of this law claimed that Denmark was the first country in Europe to meet all the requirements of Article 3 of the SAVE Directive 93/76 / EEC, E.V.V.E. (1998). Even before the legislation was introduced, IMC was used in approximately 75% of the housing stock (Abrahamsson, 2013). According to Energitilsynet, which was the name of the Danish energy market inspectorate until 2018, a duty for a developer to establish individual measurement in new buildings and to a certain extent also in changes in existing buildings was introduced in 2014, in the Building Act, § 7. The law says that in new buildings and new installations of heating systems in existing buildings, heat energy meters must be installed for measuring the consumption of heat in the individual housing or business unit. In existing buildings, heat energy meters or heat distribution meters must be installed for measuring the consumption of heat in the individual housing or business unit (sub paragraph 2). In existing buildings, when replacing meters or meter system, heat energy meters rather than heat distribution meters must be installed if it is technically feasible and cost-effective (sub paragraph 3). In properties with several residential or commercial units heated by district heating and in heat exchanges that serve several buildings, meters must be installed for settlement measurement of the consumption of heat at the delivery point (subparagraph 4) (Fjernvärmen, 2016). The Danish Energy Agency defines cost-efficiency as when the energy savings throughout the life span of the meter will be higher that the investment of installing and purchasing the meter. According to JRC Housing Europe Draft (JRC, without year), there is usually a high share of fixed cost in the district heating fees in Denmark, and with small part of variable costs in the price model it is hard to finance the installations of metering through energy savings.

The Celsius Smart Cities is a EU-project funded by the European Union's Seventh Framework Programme for research, technological development and demonstration. The project published a talk about "Views on private DH metering" in 2017-04-19 on the project website with a rather critical approach to IMC of heat concluding that *not having* compulsory IMC leads to a number of advantages such as the following (Celsius Smart Cities, 2017):

- **Places investments better than IMC**: It is the landlord, not the tenants, who control energy consumption in a building through controlling the standard of the heating system, the level of insulation and the standard of maintenance and renovation of the building. If the tenants pay for heating, the landlord gets less incentive to increase energy efficiency.

- **Creates a better market power balance between supplier and customer** (landlord or cooperative)
- **Enables better price models**: If the apartment owner becomes the end customer, one cannot use equally complex pricing models as for larger property owners.
- **Solves the problem on energy poverty**: In Sweden the heat is included in the rent, which means that the tenant does not have an agreement with the district heating company himself and thus cannot come up with financial insolvency with the supplier of heat.
- **Simplifies administration**: With fewer end users follows less administration and lower costs coupled to administration.

Thus, if individual metering and charging is introduced, the incentive structure is changed and the tenant is given incentives to save energy, while the property owner loses the incentive to carry out energy investments. Denmark (like Germany) has rules on how much of the energy cost is to be charged based on the meters and how much can be charged based on the standard/apartment size (Boverket, 2017).

The use of district heating substations at every flat in a multifamily building would automatically mean that the IMC requirements would be fulfilled. If flat stations were to be used, the need for hot water circulation disappears in apartment buildings, since this recirculation simply moves into the district heating network (Averfalk & Werner, 2017). The fact that the requirements for IMC will be met by the use of flat stations, might however, not outweigh the problems with increased investment costs for the purchase of the equipment that in most situations would be larger than investing in energy meters at every flat (Persson & Kruber, 2015).

2.5 Functional requirements of meters and communication systems

In this subchapter, features that are important to consider when choosing meter and communication system are listed. The findings are based on information from meter companies or companies working with smart metering. The features can be divided into four different categories; technical functionality, security and personal integrity, analytics, and business development.

2.5.1 Technical functionality

Functional requirements mean the requirements that must be fulfilled in order to be able to collect meters and measured values. The functional requirements that can be described in the form of technical requirements and is for example:

- **Communication range** (Kamstrup, 2019a; Ambiductor, 2019)
- **Flexibility/Independency of other networks,** for example mobile grid or electricity grid (Ambiductor, 2019)
- **Immunity from interference from other devices**. When using PLC some problems have occurred with increased use of home electronics that affects the same frequencies which the PLC technology uses to send data. As new appliances (for example LED lamps, induction hobs or heat pumps are connected to the mains), the disturbances have worsened (Aidon, 2016).

2.5.2 Security and personal integrity

There are basically three areas of importance concerning security and personal integrity: the risk of measurement data being manipulated or modified; the risk of unauthorized persons gaining insight into the customers' energy consumption; the risk that control functions such as control of switches can be used by unauthorized persons (Tieto, 2014; Ambiductor, 2019). Data encryption, role-based access to data, logging of activity, multiple security layers and contingency plans are examples of important features in metering solutions addressing the problems with security and personal integrity (Kamstrup, 2019b).

2.5.3 Analytic requirements

The analytical requirements can be set based on which analyses the district heating company wants or wishes to carry out. It can require measurement data collection to facilitate automatic fault detection or offer energy services to customers. Examples of analytical requirements are:

- **Suitability for basic data analytics and for real time data analytics** (Ambiductor, 2019). In chapter 3, examples of different applications of use of meter readings for district heating and electricity, found in research, are showed.
- **Service quality and performance**. Service quality is often measured as a proportion of measured values or responses that are delivered within a certain time limit, for example the proportion of measured values that are collected within 9 hours after day shift, or the proportion of real-time readings delivered within 30 seconds. It must be ensured that the system has sufficient capacity to handle an increased number of meters, higher recording frequency and new services without deteriorating the quality of service (Tieto, 2014).

2.5.4 Requirements ensuring business development

Requirements for meters and communication systems must meet the ambitions that exist regarding the development of new price models and new energy service offered to the customers. Examples of business developments that can put requirements on meters and communication system are:

- **Interface to the home**. For future meters, there should be a digital interface that the end customer can use to access their energy consumption locally. The communication solution should also support a future standard for communication with devices in the home (Tieto, 2014; Swede Energy, 2018).
- **New requirements with new price models.** For example, components in price models based on hourly load require that energy meter settings at hourly level can be obtained. Components based on return temperature should be based on instantaneous read hourly values (Swedenergy, 2019).

A fundamental requirement for meter and communication system is to meet the requirements set in the present price model ensuring that customers are billed according to real measured values. When charging the customer for the consumed heat all charge-based parameters should be based on actual measured values from the thermal energy meter according to Energy Markets Inspectorate’s regulations in Sweden mentioned earlier.

Today, new more complex district heating price models are being developed towards models that better reflect the district heating companies' costs for producing and delivering the heat to the customer in order to reduce economic risks that comes with variable heat demand and high shares of fixed assets. The keywords in the new price models are higher shares of fixed cost, seasonal energy prices and charging for capacity. Some district heating companies have also included components in the price model that serve as incentives for customers to make certain behavioural changes, such as load components and flow components (Sernhed, Gåverud & Sandgren, 2017). There are large regional differences in price models for district heating in Sweden. This is for example shown in a study by Song et al (2016), where 237 pricing schemes were collected and classified at 80 Swedish district heating companies into four different price model components (the yearly heat production from these 80 companies accounted for the major part - 85% - of the total heat production from district heating in Sweden). The components proportion of the total price to the customer was calculated for a typical multifamily house with a yearly heat consumption of 193 MWh, see **Fel! Hittar inte referenskälla.**.

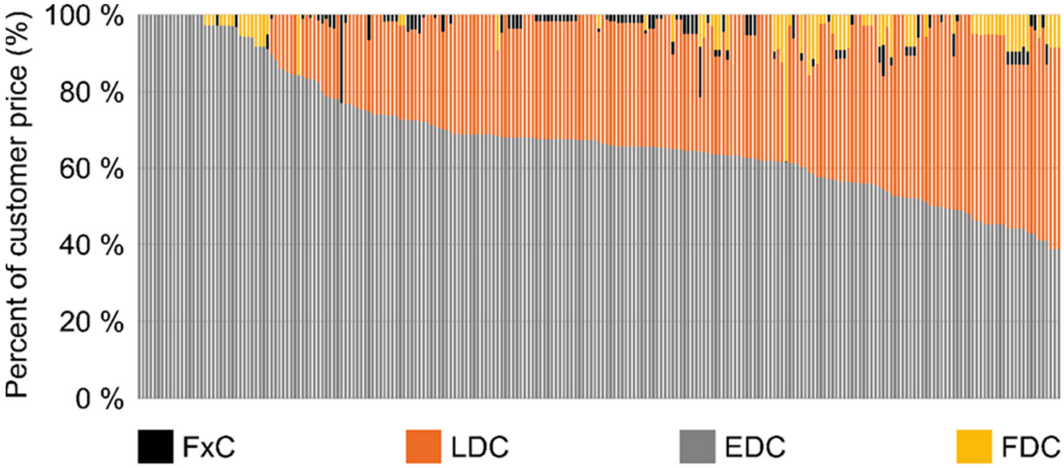

Figure 2. Proportion of price components in cost calculation of template building upon 237 pricing schemes as presented in Song et al. Grey bars shows the share of the cost for energy demand components (EDC) in the schemes. Orange bars shows the share that comes from a load demand component (LDC). Yellow bars show the share that come from a flow demand component (FDC). Black bars show the share from the fixed component (FxC).

As can be seen in **Fel! Hittar inte referenskälla.**, most of the companies included in the study from Song et al had load demand components in their price models (although based on several different principles). In Song et al, five different pricing principles of charging for capacity were identified:

- To determine the load demand by using the customer's total consumption during a certain period of time - either during the previous year or during the previous high peak period.
- To assign the customer consumption hours per year (or winter period) to different customer categories (typically 2200 hours per year for multifamily houses) and then divide the actual consumption of that period by the assigned consumptions hours. This is called the "category number method" and is the most commonly used method to decide a load component amongst the Swedish district heating companies.
- To use the correlation between customers' historical heat consumption and the outdoor temperature to predict customer consumption at extreme weather condition through simple linear regression. This method is called the "Load Signature Method".
- To let the customer's measured peak load determine the level of the fee. The fee could either be based on the highest peak or on a mean value of several peaks of a certain period (often the debiting period).
- To let the customers subscribe to a certain load level at which the customer will pay a relatively low variable price for energy. If the subscribed load level is exceeded, the customer will pay a higher cost for the energy exceeding the level.

Flow demand components were not as commonly used. Approximately one third of the companies used flow demand components. For flow components there are basically two models used for charging for flow used by the Swedish companies, according to a study by Petersson & Dahlberg Larsson (2013). The district heating company can either use a fixed price for each cubic meter water that passes through the customer's district heating substation or they can use a bonus malus system where customers with poor cooling will pay a fee which in turn is used to pay a bonus to customers with good cooling. The fees can be charged either throughout the whole year or during the heating season only. A few district heating companies have introduced a correction factor to compensate for lower supply temperatures in the periphery of the grid. The lower supply temperatures make it harder for the customer in the periphery of the grid to achieve good cooling, meaning that these customers would be disadvantaged by the price model if no correction factor was used. The problem with the correction factor is that it makes the price model more complex for the customer to understand (Sernhed et al, 2017).

There are also examples where district heating companies charge for the cooling instead of using a flow component in the price model. In Danish Hofor, a cooling requirement has been set which lies between 25 and 31 degrees Celsius depending on district heating area (Hofor, 2019a; Hofor 2019b). If the cooling in the customer's substation is up to five degrees Celsius higher or lower than the actual reference value, no extra payment is required. If the cooling is five degrees or more than the requirement, the customer receives a bonus, while if the cooling is five degrees or more less than the requirement, the customer instead has to pay extra.

2.5.5 Outlook on requirements for electricity meters

The development of automated meter readings (AMR) and smart meters has been faster in the electricity industry than in the district heating industry as a result of the implementation of the legislation on billing based on actual consumption that came in 2009 in Sweden. Since the development of the electricity industry in this area lies ahead of the district heating industry, it might be interesting to look at the functional requirements for electricity meters and discuss whether similar requirements can have a counterpart on the district heating side.

New requirements for electricity meters in Sweden have been developed by the Swedish Energy Market Inspectorate. The new requirements are summarized in a report from the Swedish Energy Market Inspectorate (Swedish Energy Markets Inspectorate, 2017) and encapsulated in an English summary (Swedish Energy Markets Inspectorate, 2018). The new functional requirements were decided at the end of June 2018 by the Swedish government and meters with the new functional requirements must be in place no later than 1 January, 2025 (Government offices of Sweden, 2018). The suggested functionalities are presented in Table 1.

Table 1. Description of seven suggested functions/functionalities for electricity meters. Source: Swedish Energy Markets Inspectorate (2018)

No.	Functionality	Purpose
1	The meter should for every phase be able to measure voltage, current, active and reactive power for withdrawal and input of electricity. The meter should also be able to measure and register the total energy for withdrawal and input of electricity.	Promotes efficient network operation. Facilitates integration of micro production in the network.
2	The meter should be equipped with a customer interface, supported by an open standard, for the customer to be able to take part of the measured values (see functionality no. 1) in near real time. It should not be possible to send information to the meter through the interface. The interface needs to be activated by the DSO, on request by the customer, to provide information. The DSO should control the identity of the user and must deactivate the interface when the customer moves out.	Creates conditions for a developed energy services market. Promotes demand side flexibility and energy efficiency. Increases customer empowerment.
3	The DSO should be able to read the measured values (see functionality no. 1) remotely (with remote control).	Promotes efficient collection of meter data.
4	The meter should be able to measure the energy for every hour and be able to convert to measure the energy for every fifteen minutes.	Increases the customer's possibility to be active (participate) in the market.
5	The meter should be able to register data about the beginning and end of a power outage in one or more phases, that is three minutes long or more.	Facilitates for the DSOs to pay compensation to the customer for interruptions longer than 12 hours and to report data to Ei. Empowers the customer.
6	The DSO should be able to update software and change settings of the meter with remote control.	Provides that new functionalities can be introduced in a cost-efficient way. Expensive field visits can be avoided.
7	The DSOs should be able to turn on and off the power through the meter with remote control. This requirement only applies for meters that are not transformer connected.	Facilitates for the DSOs to turn off the power if the customer moves out. Expensive field visits can be avoided.

The seven suggested functionalities for electricity meters and metering might be used as inspiration when trying to set the path for future heat metering. Not all of the mentioned suggestions are applicable for district heating, but some are – either directly or indirectly. In the following paragraph, the functionalities 1-7 are discussed from a district heating point of view.

1. The first point, concerning the measuring of energy withdrawal (or input), might very well be transferred to DH-meters, only substituting the units. Instead of voltage, current and power, more relevant data to measure for DH is flow and temperature (supply and return), which in turn can be used to calculate energy and power consumption. This, of course, is already measured today. Regarding prosumers, mentioned in the purpose above, this is relevant also for district heating. Buildings with a high cooling demand will at some periods produce an excess of heat, which can be fed into the DH grid and needs a means for measuring.
2. The possibility for customers to take part of measured values in a standardized way (for example M-bus interface) is equally interesting for district heating. Not only does this allow the customers to get a better overview of their (real time) consumption, but also opens up for a better regulation of the customer substations. This might in turn be used to create business models where, for example, the peak power can be regulated and reduced. Some meters today come with an extra slot, ready to implement this functionality.

For example, the local district heating company in Eskilstuna in Sweden supplies all new DH meters with an M-bus output for all commercial customers since 2017 (Eskilstuna Energi och Miljö, 2018).

3. Exactly the same principle is relevant also for district heating in order to efficiently collect meter data without the need to physically visit the meter.
4. Due to the thermal inertia and slow reaction times of both district heating systems and the secondary systems at building level, a higher resolution than hourly values might not be necessary. However, a possibility to temporarily increase the metering frequency may be useful in order to diagnose malfunctioning substations.
5. To automatically be able to detect interruptions or other disturbances in the heat delivery is an interesting feature, which however most likely requires the differential pressure over the meter to be measured, which is not the case today. Today, there is no functional requirement for district heating set in any law and there is also no industry-wide definition of a district heating interruption. There is, however, an ongoing discussion between the Swedish Energy Agency and the Swedish District Heating and Electricity Association (Swede Energy) about security of supply and how disruptions in deliveries should be defined for district heating. The cooling of buildings in the event of an interruption in the supply of district heating is relatively slow even in cold weather due to high heat inertia in buildings (at least in buildings built for colder climates). In the district heating network there is also a certain inertia built in, a time delay. After an interruption in the production or distribution, a lot of heat remains in the large volumes of hot water found in the district heating network. The heat inertia of the buildings and district heating network means that the end users do not always notice that an interruption has occurred. In some cases, when the temperature of the water in the district heating network has dropped, the quality of the delivery can be maintained and compensated with an increase in the flow. An interruption in the delivery of district heating, on the other hand, is immediately noticed at the temperature of the domestic hot water. Operations that are dependent on domestic hot water are therefore not "protected" by the intrinsic heat inertia of the buildings or district heating network (Swede Energy, 2018 – referral 2018-03-23). A distinction is made in this referral between supply security and power quality, where supply security refers to the ability to supply heat energy without interruptions and where power quality refers to the ability to deliver heat energy within given limits regarding pressure and temperature (ibid).
6. The possibility to remotely upgrade the meters’ software may open up for new services and business areas for district heating companies. Also the possibility to remotely change meter frequency is desirable.
7. This is a functionality that would be difficult to apply for district heating as the heat delivery must be physically shut down.

All in all, new and/or improved functionalities for heat meters opens up for new possibilities for both customers and DH companies. It may allow for automated fault detection, new deals and services to customers, more precise business models and new potential areas of business for DH companies.

2.5.6 Ongoing work on standards for validating measurement data

Automated meter readings on the electricity side has largely been guided by mandatory rules in Sweden, which has led to a homogenisation of how electricity metering is carried out. For district heating industry, uniform requirements for measurement were first in place in 2015. This has led to a wildly grown flora of measuring systems and principles according to an article in the magazine ENERGI (Tidningen ENERGI, 2018 vol 1). There is a plethora of different measurement systems for district heating from different generations, which is due to the fact that the Swedish district heating companies were early testing new systems with many pilot projects being launched the last 20-30 years (ibid).

SIS/TK 601 is the name of an ongoing standardization project for heat meters in Sweden with the aim to create a standard for validating measurement data to meet future requirements from directives and consumers. By doing this, the industry hopes to create greater trust between authorities, energy companies and rental and tenant-owner associations. Today, there are problems with incorrect measurement data, due to for example faulty energy meters or communication equipment - errors, that if remained undetected can become costly and can make the industry lose credibility when customers discover errors and receive incorrect invoices. Since there are no guidelines for how to validate measurement data today and the regulations developed by the Energy Market Inspectorate in EIFS 2014: 2 can be interpreted in different ways, the district heating companies use various ways to validate the data. Because of this, a need to standardize the validation methods of measurement data has been identified (Swedish Standards Institute, 2019).

Depending on the price model, different requirements are set for measurement values and measurement frequencies. Load components based on hourly load will stress the demands on the energy meter setting so that hourly level data can be obtained. Flow components based on return temperature also need to be based on instantaneous read hourly values. According to a telephone interview with Marie Skogström who sits on the committee for the standardization work SIS TK / 601 on heat meters, there will probably only come recommendations, and not fixed requirements, for the measurement frequency on new meters due to the large variety of price models used by the district heating companies.

3 Applications of data analysis

Smart energy meters with frequent metering gives rise to many alternative uses for data analysis. In this chapter, an overview is made in which different areas hourly values or even more high-resolution values for energy consumption are used for data analysis of the electrical industry and the district heating industry.

The chapter starts with pinpointing one area of use that is of particular importance for low-temperature district heating systems, namely the need to attain low return temperatures in the district grids. Therefore, a special focus is placed on describing the need to lowering the return temperatures in the district heating grid, as well as to describe how Danish and Swedish district heating companies are working to lower the return temperatures today. After this, the result from a literature study that has summarized a large number of scientific articles on various uses for data analysis in the electricity field, is presented. Then, a selection of projects (some Swedish projects and some EU projects) is presented, that in different ways touches on data analysis of measured values from energy use of district heating. Some examples of commercial products, which has been developed in the wake of the different research and development projects, are also addressed.

The purpose of this exercise is to show examples of different areas of applications for data analysis that are being researched today and to try to gain an understanding of future measuring needs - if this can be determined.

3.1 The importance to work with low return temperatures

There are many benefits of reducing the system temperatures in a district heating (DH) network. Reducing the system temperatures increases the overall efficiency of the system and decreases the heat losses, resulting in economic and environmental benefits. According to a study of 142 Swedish district heating systems, the average conventional Swedish DH system has a supply and return temperature of 86°C and 48°C respectively. However, these temperature levels could theoretically be much lower using known substation technology (Frederiksen & Werner, 2013).

The return temperature depends on several parameters: supply temperature, heat losses in the distribution grid and the cooling in the substations. The supply temperature is set by the DH company according to the required heat load. However, it is somewhat dependent on the return temperature since there must be a certain difference between the two temperature levels to be able to distribute sufficient amount of energy to the customer according to the formula:

$$Q = \dot{m} * Cp * dT$$

Q = Energy
$\dot{m}$ = Mass flow
Cp = Heat Capacity
dT = Temperature difference

The mass flow rate of the water in the pipes is limited by the dimensions of the pipes and Cp is a constant. Hence, if the return temperature is too high, the supply temperature must be increased (Fredriksson, 2015). An increase of the supply temperature level can be a very costly measure depending on the size of the grid and the source of heat production (Brange et al, 2017). It is therefore of utmost importance to have a satisfying cooling of the district heating water.

3.1.1 Examples of common faults in substations

The return temperature is, as mentioned above, affected by several factors. The supply temperature is set by the district heating company and depends mainly on the outdoor temperature (and in some cases on more dynamical control based on load prognosis and production planning). The distribution heat losses will decrease as the temperature decreases. The most relevant problem to address is therefore the cooling in customer installations and the district heating substations. Unsatisfactory cooling of the district heating water in a customer substation can be linked to any of the substation’s components, for example the heat exchanger, the control system or valves or the internal heating system for space heating (SH) or domestic hot water (DHW).

The main issues that can occur in the heat exchanger are for example dirty heat exchanger plates, leaks and incorrect installation. Incorrect installation means that the district heating water and the internal heating system flow parallel to each other instead of opposite directions. When the water flows in parallel, the efficiency of the heat transfer is greatly reduced (Månsson, 2018).

A substation has control systems that regulate flow and temperature based on the demand of the internal heating system. If these control systems do not function correctly, the cooling of the district heating water will be affected. A common fault is incorrect installation of the substation, for example by setting inappropriate set point values for flow and temperature. If the set point value for temperature is too high and too close to the district heating supply temperature, the flow will increase through the heat exchanger and decrease the possibility for cooling and thus increase the district heating return temperature. Another mistake is to install the temperature sensor for the DHW too far away from the heat exchanger. This is especially noticeable when there is no hot water circulation as the DHW will then cool down after some time if it is not used. The sensor will sense this dip in temperature and interpret it as if more DHW is required. If the sensor is located far away from the heat exchanger, it will take quite some time before the set point temperature level is reached resulting in over production of DHW (ibid).

Furthermore, there is a risk of the control valves getting stuck in an open position imposing a greatly increased flow through the heat exchanger. This can be caused by either worn out valves or if the control valves are oversized in relation to the heat demand (ibid).

A customer’s internal heating system can be divided into two parts: the domestic hot water system and the space heating system. The issues are usually found in the DHW system. Apart from the inevitable wear on an old system, the problems can often be related to the way the system is designed, i.e. if there is hot water circulation (HWC) or not. Circulation can cause a problem if the district heating substation is connected in parallel because the circulation pipe may then be connected to the cold water pipe, decreasing the cooling capacity in the DHW heat exchanger. The HWC may also increase the flow in the DHW system, preventing proper cooling (ibid).

3.1.2 Experiences from Denmark

In order to investigate how Danish district heating companies work with cooling in substations, a survey prepared by the authors of this report was sent out to over 300 Danish district heating companies. The names and contact information were found on the Danish District Heating Association homepage. The survey focused on if, why, and how the DH companies work to lower the return temperature. The survey was created in Google Forms and was sent out as a link together with an email describing the COOL DH-project and the purpose of the survey. Around 10 % of the contacted companies responded to the survey (32 companies).

Working with reducing the return temperature was seen as an important matter

Almost 90% of the respondents stated that there was room for improvement concerning their return temperature, 26% even said that significant improvement was required. The main incentives for the companies to reduce return temperatures were to decrease the heat losses in the system and to increase the efficiency of production. A clear majority, 78%, of the respondent district heating companies answered that they are currently working actively to reduce the return temperatures.

Automatic versus manual fault detection

Remote reading of key parameters can be a time effective way of identifying poorly functioning substations and this is also the method most used by the Danish DH companies. However, a significant number of companies stated that they discovered malfunctioning substations manually by manual search or by chance while doing service visits. Even some companies who stated that they weren't actively working to reduce the return temperatures, identified customers with malfunctioning substations using both customer data analysis and/or during visits. All the companies who stated that they were actively working with fault detection said that they contacted the customer after identifying their malfunctioning substation and it was common to either advise the customers on how to proceed or even to offer free service to those that needed it. Only 25% of the answering DH companies stated that they offered service agreements to their customers, but an additional 20% of the companies offered service if the substation had been identified as having poor cooling.

Incentives in price models

The Danish DH companies were asked if they had a flow component in their price model and the majority replied that they did not; less than a third said that they charged for flow specifically. In a free text section, the respondents had the possibility to elaborate on their answers and two of the companies that stated that they had a flow fee explained that the component was actually a return temperature fee instead. In total, five companies (16%) indicated that they had a return temperature fee as an incentive for the customers and some stated that they were planning to introduce penalties for poor cooling in the future.

Discussion about the results of the survey

Even though fewer companies than hoped filled out the survey - 10% - and it is therefore difficult to draw any conclusions about the study's generalisability for Danish district heating companies, it is clear that working with lowering the return temperature is seen as an important matter for the district heating companies.

Interestingly, even those who stated that their supply and return temperatures were already quite low, around 65°C for supply and 35-40°C for return flow were not satisfied with their cooling and were actively working to reduce the return temperatures.

It can also be concluded from the answers in the survey that most district heating companies had the same approach on how to improve return temperatures. The malfunctioning substations are most often identified by remote reading of key parameters such as flow and difference between supply and return temperature (delta T) and the customers are then contacted to be made aware of the problem. Many companies also offer either advice on how to proceed, or offer to perform maintenance on the substation in question. A question that wasn't asked but would have been interesting to follow up on is if or how they work preventatively with the customers, i.e. if and how information is spread to the customers on how to properly maintain the substation and the impact this can have on the district heating system.

3.1.3 Experiences from Sweden

In 2018, Månsson performed an interview study with six different district heating utilities in Sweden, in order to investigate how they were working on the topic to reduce return temperature from connected customers. The district heating companies that were included in the study were chosen on the basis that they had shown very good values for cooling and therefore should be companies that work actively to achieve low return temperatures. The study focused on how to identify and how to encourage customers to correct malfunctioning substations. Some of the interviewed companies had a component in their price model related to return temperature performance of the district heating substation. The experience from the companies with flow component in their price model, was that the flow component itself was not sufficient as incentive for the customers to work actively with reducing the return temperature, since the contribution of the cost of this component was only a small part the total cost for energy. However, the interviewed utilities with flow components pointed out that the component itself increased the customers interest on the topic of reducing the flow through the substation and thereby the return temperature (Månsson et al, 2018).

On the topic of identifying customers with poorly performing installations it was concluded from the interview study that all companies did some analysis of measured data from the energy meter in a structured way. The analysis could consist of monthly checks of consumer billing data, quality index, analysis of return temperature level or flow. Also an overconsumption method was used as a method for detection of poorly performing customer installations by some of the utilities. Even though most of the interviewed utilities had some sort of identification of poorly functioning substations, the key factors to success regarding fault handling in customer installations could be expressed in terms of customer relation and communication. According to Månsson et al, the key factors to success regarding fault handling in customer installations are:

- Physical access to customer installation
- Achieving and maintaining good customer relation
- Have clear arguments for customers to correct malfunctions causing high return temperatures in their DH substations

It is clear that the district heating utilities have incentives for improving the customer installations and that the utilities use data from the energy meter as indicator of the performance. By offering service agreement to district heating customers the three mentioned key factors can be fulfilled. However, the identified success factors do not involve increased data analysis. The key to success can be summarized as customer relation. By offering service agreement, technicians from the utility can be given access to customer installations on a regular basis and opens up for discussion and arguments for improved performing of the substation and at the same time it may improve the customer relationship (ibid).

Example from the Swedish district heating company Kraftringen AB

Kraftringen's district heating customers have the possibility to enter an agreement with Kraftringen for maintenance of the substations. These maintenance visits are performed once a year for private customers and twice a year for larger customers and help to ensure the state of the substations. In the case of the larger customers, some spare parts are included if a fault is found that requires reparation. For private (household) customers no spare parts are included in the deal. Since there is no flow component in the price model for private customers, these customers do not have an incentive to make repairs recommended from the service visits according to the responsible personnel for service agreements. Corporate customers, on the other hand, are more likely to accept the cost of the repair, as the cost might be significantly lower than what the overconsumption is costing them through the price model. A service agreement is a good way for Kraftringen to keep track of the substations and also to meet the customers. Unfortunately, a large portion of the customers, both private and corporate, chose not to have a service agreement.

Kraftringen measure overconsumption by measuring the difference between supply and return temperature, the energy used and the flow through the heat exchangers, in all the substations in their network. A list is compiled weekly of the top ten of the customers having the highest return temperature together with the highest energy consumption and these customers are then visited regardless if they have the service agreement or not (Sjöstrand, personal communication, 2019).

3.2 Study of applications for data analysis from electricity automated meter readings

The use of smart energy meter values for analytics in district heating applications is in an early stage of development compared to usage of data in the field of electricity and electricity networks. In 2016, Trindade et al conducted a literature study summarizing different studies where automated metering readings for electricity had been used in different applications (Trindade et al, 2016). Since there might be many similarities between the electricity smart meter applications and smart meter applications for district heating a table summarizing the applications, data requirements and data analysis approaches from this study is shown here, see Table 2.

Table 2. Potential applications for data analytics and data requirements, Trindade et al (2016)

Application		Data Requirements	Data Analytics Approaches
Planning	Correction of topological error in database	• Voltage magnitude active and reactive power from smart meters	Descriptive
	Equipment diagnosis/asset management	• Power quality data • Hours in service of the equipment • Frequency of overloads • Time spent overloaded	Descriptive Predictive Prescriptive (and Predictive)
	Prediction of customer consumption considering changes in actions	• Customers behaviour information • Load data • Weather data • Price and tariff information	Predictive
	Power quality management	• Oscillography from meters installed along the feeder • Power quality data e.g. total harmonic distortion flicker index	Descriptive Predictive Prescriptive (and Predictive)
	Integration of Renewable Energy sources (RES)	• Weather data e.g. irradiation wind speed and direction • Load data • Other field measurement data	Descriptive Predictive Prescriptive (and Predictive)
Operation	Outage management	• Customer calls • Geographic information • Oscillography from meters installed at substation or along the feeder • Status of sentry devices installed along the feeders • Time-of-outage • Telemetered fault indicators • Voltage magnitude from smart meters • Weather data and/or lightning strike positions	Descriptive Predictive Prescriptive (and Predictive)
	Unit commitment	• Customers behaviour information • Load data • Power generation data • Price • Weather data	Predictive Prescriptive (and Predictive)
	Detection and location of non-technical loss	• Load data - • Voltage magnitude active power and reactive power from smart meters • Social and economic data • Alerts provided by the smart meters	Descriptive Predictive Prescriptive (and Predictive)
	Demand response	• Customers behaviour information • Load data • Information of the customers' appliances • Price and tariff information • Weather data	Predictive Prescriptive (and Predictive)
	Detection and location of high impedance faults	• Voltage magnitude active power and reactive power from smart meters • Oscillography from meters installed along the feeder	Descriptive Predictive Prescriptive (and Predictive)

Trindade et al describes three main approaches for data analytics: descriptive-, predictive-, and prescriptive approach. The descriptive approach describes a projection of what will happen. The predictive approach answers how to deal with it. It can be by using predictions for one or more alternative scenarios. Finally, the prescriptive approach goes further than just prediction of trends. Within the prescriptive approach, outcome from one or a series of actions can be predicted and recommended. The prescriptive approach can be used to determine the outcome from different actions. In the article, Trindade et al describes some potential applications for data analytics and data requirements (the ones shown in Table 2). Some of these applications may be interpreted within a district heating context and can be identified in ongoing projects.

3.3 Projects

There are several ongoing projects in the area of efficient district heating and low temperature district heating systems. Even though the main focus may not be the same in the different projects, all of them are aiming at increasing the performance of district heating customer installations in one way or another. The aim can be to find both technical solutions to make load predictions, detect and analyse malfunctions in customer installations and/or to develop good routines for district heating companies to continuously work with finding and fixing malfunctioning substations. Common for all these projects is the use of meter data from customer installations and automated processes to continuously work with improved performance of the district heating system and to reduce the primary return temperature. For this purpose, heat meter readings are used as main source for analysing the performance.

3.3.1 STORM

The STORM project, which is a Horizon 2020 project, started in 2015 and is just about to finish. The STORM project started out from state of the art technology for modern 3rd generation district heating systems. The aim of the project is to develop a district heating network controller, the STORM-controller, that is applicable for state of the art 3rd generation district heating as well as for innovative low temperature district heating systems. In the STORM-controller modules for forecasting, planning and demand side management are implemented in order to benefit the whole energy chain. The modules are based on self-learning algorithms with input from DH meter readings from connected customers. Within the STORM-controller also market interactions between heat and electricity market for optimization of heat and power production is included. Within the STORM project the controller has been implemented at two sites, Heerlen in the Netherlands and Rottne in Sweden. Some real output from the demonstration sites is reduced usage of peak district heating production with 12-13%. In Heerlen new district heating customers has been connected to the district heating network through benefits from cell balancing groups of customers. From an academic point of view, the project has developed methods and algorithms for load prediction by using deep learning, see for example Vanhoudt et al. (2017 b), Geysen et al. (2018), Suryanarayana et al. (2018). (STORM, n.d.; Vanhoudt et al., 2017 a; Johansson C., Phone contact 2019-03-28)[1]

3.3.2 TEMPO

TEMPO started in 2017 and is an ongoing EU Horizon 2020 project until 2021. The focus within the project is on low temperature district heating in Europe. The aim is to develop technical innovations enabling low temperature district heating with focus on individual building- and network optimization. Within the scope of individual building optimization, the performances of the substation and the buildings' heating installation are in focus. Faults in building

[1] Johansson, Christian, NODA, Phone contact 2019-03-28. Johansson is Chief Technology Officer and co-founder of NODA. NODA is one of the partners in STORM.

installation and district heating substations needs to be identified, which is a part of the technical innovation for the TEMPO-project. In the first stage, hourly meter readings from customers and data for outdoor conditions will be used for fault identification[2]. The network optimization is divided into two innovations, one for optimising the functionality of bypasses in district heating substations and one for optimization through digitalisation. One of the outputs in the innovation of network optimization through digitalisation is ICT-platforms suitable for different users, both expert users and non-expert users. Johansson, Chief Technology Officer at NODA and partner in TEMPO, stressed that the ICT-system should be used as a tool for decision support for expert users, and for non-expert users the ICT-interface should give information of energy consumption and system performance in a larger energy system context. (TEMPO, *Project Outline,* 2017 a), (TEMPO, *Network Optimisation – Digitalisation,* 2017 b), (Johansson C., Phone contact 2019-03-28)[2]

3.3.3 K2 - Smart Energi (Smart energy)

K2 is a collaboration of eleven Swedish district heating companies and one consultant company. The aim of the collaboration is to develop a platform to analyse energy usage and consumption. The final outcome of the project is still unknown, since it is an ongoing project with continuous developments. Within the project, methods for automatically identifying malfunctioning heat meters and to identify energy losses and anomaly functioning substations, are being developed. K2 - Smart Energi has recently received funds from Future Heat (a Swedish research program) to create a database with anonymous hourly meter readings from real district heating consumers with free access for researchers and universities[3].

3.3.4 SeMi - Self-Monitoring for Innovation

SeMi is a Swedish project founded by the Swedish Knowledge Foundation, that provides funding for projects conducted in collaboration between partners within the academic sector and the business sector (KK-stiftelsen, n.d.). One of the aims within the SeMi project is to develop methods and algorithms for detection of malfunctions or anomalies in district heating substation performance (Halmstad University, 2017). The scope is to, through automated methods in real time, find malfunctions and predict faults by using IoT and a machine learning approach (Halmstad University, n.d.).

Some outcome of the project so far, presented by Calikus et al. (2019), is automatically methods for clustering district heating customers by analysing load profiles from hourly data from the heat meter. The approach used by Calikus et al. (2019) also identifies customers with load profiles that are abnormal or doesn't fit in to their category.

3.3.5 DAD - Data Analytics for Fault Detection in District Heating

DAD is a research project focusing on automated monitoring and optimization of district heating systems through automated analysis of data collected at the district heating customers. Some of the research areas are on-line detection of abnormal behaviour of customer installations, detection of sub-optimally adjusted or malfunctioning district heating installations and classification and detection of abnormal behaviour. Partners involved in the project are University of Borås, AB Bostäder (in English: Borås municipal housing company), Borås Energi och Miljö (the local

[2] Johansson, Christian, NODA, Phone contact 2019-03-28. Johansson is Chief Technology Officer and co-founder of NODA. NODA is one of the partners in TEMPO.

[3] Gadd, Henrik, Öresundskraft AB, Phone contact 2019-03-14. Gadd has a position as business development at Öresundskraft AB. Öresundskraft AB is one of the involved partners within K2 project.

district heating utility in Borås) and NODA Intelligent Systems. The project started in 2018 and will end in 2020. (University of Borås, 2018).

According to Christian Johansson who represents one of the collaboration partners within the project, the DAD project has an academic approach and has a lower level of technology readiness compared to the STORM project. One of the desired outputs is more knowledge concerning machine learning algorithms[4].

3.3.6 SCA - Smart Cities Accelerator

SCA is an ongoing EU Interreg project with partners in Sweden and Denmark. The project started in 2016 and is prolonged to 2020. The project aims at, through collaboration between universities, other institutes for higher educations and six municipalities in Sweden and Denmark, generate innovations for a sustainable future. One scope within the project is to reduce district heating temperatures in existing district heating networks to obtain increased system effectiveness. The project highlights the importance of well performing district heating network, district heating substations and customer installations. Within the project, a joint innovation call on the topic "Securing lower forward temperature in district heating, still satisfying the end-users" with the aim of identifying poor performing DH-substations, tools to analyse malfunctioning substations and temperature optimisation, has been conducted. (Kraftringen, n.y.; Smart Cities Accelerator, n.y.; Climat-KIC, n.d.).

3.3.7 SAM – Smart Asset Management

SAM, or Smart Asset Management, is an innovation program partly funded by Vinnova[5] and led by SweHeat & Cooling (Vinnova, n.d.). The program started in December 2018, and gathers 31 different partners (SweHeat & Cooling, n.d.), including district heating companies, suppliers of technical equipment and universities under a common purpose to find partial solutions to a number of questions regarding the aim to move towards the fourth generation of district heating. The focus point is the transformation of existing networks, both renovations in the grid and actions on the customer side. In this project, the key words are "continuous improvement" where tools like algorithms, digitalization, and new sensors and materials are being developed and implemented. Also taken into consideration is the development of new business models and strategies for district heating companies.

The project includes two main focus areas: firstly, the refurbishment of the distribution network, and secondly the customer heat transfer units and the secondary heating systems. The theory is that 80 % of the issues regarding the secondary systems is caused by 20 % of the customers, which is why the most critical costumer installations are to be identified and fixed each year in a continuous cycle. How this is done is up to the district heating companies, but SAM suggests a 4-step cycle:

- Condition monitoring – measuring and understanding
- Optimization
- Replace defect parts

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[4] Johansson, Christian, NODA, Phone contact 2019-03-28. Johansson is Chief Technology Officer and co-founder of NODA. NODA is one of collaboration partners in DAD.

[5] Vinnova is a Swedish authority under the Ministry of Trade and Industry. Vinnova is the Swedish Government's expert authority in innovation policy. Vinnova is also Sweden's national contact authority for the EU's framework program for research and innovation. (https://www.vinnova.se/en/about-us/swedens-innovation-agency/the-role-of-vinnova/, [2019-04-10])

- Increase utilization

The first step is closely related to measuring at the customers, as customer data is used to identify the customer installations with the highest temperature requirements and lowest heat transfer (SweHeat & Cooling, 2019).

3.3.8 Green IT innovations for district heating

“Gröna IT-innovationer för fjärrvärme” (in English: Green IT innovations for district heating) was a Swedish project within the district heating research program “Fjärrsyn” carried out in 2015-2016. The project focused on how both customers and district heating suppliers could better overview and control the customers heat use through a developed technology platform placing district heating in smartphones and notebooks in a number of demonstration environments. Part of the project was about how digitization can affect the district heating business models (Sernhed et al. 2018). The initiative for the project was taken as a response to a number of district heating companies' wishes to gain access to new, digital tools to increase customer relations, improve customer communication, streamline their internal processes and in this way secure future district heating business. It was also possible to offer new digital energy efficiency services in order to contribute more clearly to the national energy efficiency goal. The project was implemented with a high degree of application of prototype installations of new, digital tools (Emanuel et al., 2016).

Results show that there is a considerable work to implement this new digitalisation platform for existing heat supply installations. Another result was a tool to estimate the true long term value of the implemented digitalisation (2). Demonstrations indicated an energy saving potential of up to 10-15% due to the fact that the end users, through real-time connection, reach insight in their energy behaviour and about the household's energy profile over time and at the same time can influence their power output through control functions in the interface. Rational remote connection service indicated that district heating companies can periodically avoid more than 20% of service calls about badly working customer installations. Experienced service personnel who participated in the demonstration activities confirmed that the estimates of savings potential "were reasonable" but no empirical studies were carried out (Emanuel et al., 2016).

3.3.9 Discussion of project applications and data requirements

In section 0 (Study of applications for data analysis from electricity automated meter readings) some applications utilizing meter readings from smart electrical meters were presented in Table 2. Since the usage of smart energy meter values for analytics in district heating applications is in an early stage of development compared to usage of data in the field of electricity and electricity networks the applications in Table 2. Potential applications for data analytics and data requirements, Trindade et al (2016) has been viewed from a district heating perspective and translated into a district heating context. In Table 3, suitable applications for a district heating content is shown, as well as how the district heating system can benefit from the applications. As seen, all applications from the electricity field could be relevant to district heating, however not all of them are identified to be in focus within the ongoing projects described in section 3.3.1 - 3.3.8. In Table 3, the column to the right indicates in which ongoing project the district heating application has been identified. The table shows that the main foci from the ongoing projects are:

- Fault detection
- Load prediction
- Production planning and optimization

All described projects are based on automated analysis of meter readings in one way or another. Many of the projects and the developed products within the projects use algorithms determined from machine learning for data analytics.

Table 3. Applications suitable for DH derived from applications identified for the field of electricity in Table 2.

Application electricity		DH application	Impact on DH	Identified in project
Planning	Equipment diagnosis/asset management	• Fault detection	• Reduced return temperature • Improved DH energy performance • Improved customer relations	TEMPO K2 SeMi DAD SCA SAM
Planning	Prediction of customer consumption considering changes in actions	• Load prediction	• Improved DH energy performance • Optimize DH production • Load balancing and prediction of peak shaving • Improve business model	STORM TEMPO SeMi
Planning	Integration of Renewable Energy sources (RES)	• Production planning • Prediction of prosumer	• Optimize DH production • Improved DH energy performance • Reduce peak load production • Improve business model	STORM TEMPO
Operation	Outage management	• Quality control through Δp & T_{ps} • Prediction of time for functioning DH at customer during outage	• Improved customer relations	
Operation	Unit commitment	• Production planning and optimization • Peakshaving	• Production planning • Reduce production cost • Reduce peak load production	STORM TEMPO
Operation	Demand response	• Customers behaviour information • Information of the customers' appliances	• Optimized DH production • Improved DH energy performance • Improve business model	STORM TEMPO
Operation	Detection and location of high impedance faults	• Fault detection • Detection of short circuit in DH installations • Detection of pipe status	• Reduced return temperature • Improved DH energy performance • Reduce heat losses	TEMPO

From the experience from the projects presented in section 3.3.1 - 3.3.8, hourly meter readings seems to be sufficient for autonomous data analysis in order to identify poor functioning district heating installations and to make accurate load predictions. During individual phone interviews with three experts on the district heating field, Marie Skogström[6]

[6] Marie Skogström, One Nordic, Phone contact 2019-03-14

(One Nordic), Henrik Gadd[7] (Öresundskraft) and Christian Johansson[8] (NODA) all claimed that heat meter data with a resolution of one hour is sufficient to identify and analyse malfunctioning substations. However, when moving on to diagnosis, a higher resolution on meter readings may be necessary. Johansson[8] and Gadd[7] describes the benefits of temporary increasing the frequency of meter readings to minute basis during diagnosis. Even though hourly metering values seems to be sufficient Gadd and Werner states in an article from 2015, that in case of low temperature district heating, as in fourth generation of district heating, a higher time resolution might be useful, but they are in the same sentence pointing out the need for increased data quality (Gadd H., Werner S., 2015).

When it comes to accessing meter parameters, some of the ongoing project and applications benefits not only from primary meter readings, but also from meter readings from the customer installations. Both Gadd[7] and Johansson[8] expressed that access to secondary meter values would be beneficial for developing algorithms for fault detection and improved performance of the district heating system. Johansson[8] suggested as a first step to add indoor temperatures as parameter for optimization and diagnosis. As a second step he suggested to add secondary temperatures measured on branches for heating system within the building. Input of requirements for metering was also gathered from district heating substation suppliers. Jönsson[9], KAM Field Sales of DH substations for Cetetherm suggested measurement of district heating differential pressure since the differential pressure is crucial for the performance of the district heating substation and the control valves. With knowledge of current differential pressure at the customer installations it open s up for possibilities for checking the quality of the heat delivery to the customer since both differential pressure and sufficient district heating temperature are crucial for the customer. Noted from the assembly in Table 3, none of the ongoing projects presented are currently focusing on this issue.

3.4 Products

There are already several commercialized products available on the market that utilize district heating meter readings to improve energy performance. The products presented in the following sections are examples of products where measured values from individual customers are used to improve the energy performance in either the individual building and or for the entire district heating system. Some of the solutions also enable the control of individual customers or groups of customers, which can be of use in the pursuit of reduction of district heating peak load production.

3.4.1 PreHeat

PreHeat, developed by Neogrid Technologies ApS (Neogrid technologies, n.d. a), is a customer oriented, self-learning tool, that uses weather forecasts and the heating properties of a building to reduce the internal supply temperatures, energy consumption and heat cost. It consists of a hardware box installed on the customers' heating system, which communicates with Neogrid's servers. The heat use in the current building is optimized using weather forecasts, current weather situations (wind, sun etc.) and expected user behaviour. The hardware is delivered with an app that visualizes the use of energy and gives access to temperature and comfort level settings. Furthermore, and more

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[7] Gadd, Henrik, Öresundskraft AB, Phone contact 2019-03-14. Gadd has a position as business development at Öresundskraft AB.

[8] Johansson, Christian, NODA, Phone contact 2019-03-28. Johansson is Chief Technology Officer and co-founder of NODA.

[9] Jönsson, Rolf, Key Account Manager (KAM), Field Sales, Cetetherm, Skype contact 2019-02-28

important in this context, is that the system detects unintended consumption, unusual heat use or high flow and alerts the user in case of such observations. In this case, the house owner or manager (in case of larger buildings) gets assistance to ensure that the system is working properly and that the return temperature always is kept at a low level. The app also helps with visualizing the economic gain from having a properly functioning system, thus increasing the incentives for the customers to take action in case of malfunctioning substations.

PreHeat also includes the possibility to offer services to district heating utilities, such as identification of bottlenecks in the network and reduction of peak loads, and acting as a bridge between customers and DH companies. It can be done using measurements from the grid and the customer substations, identifying limiting infrastructure and giving recommendations of remedial actions, either to the grid operator or the end user (Neogrid technologies, n.d. b).

3.4.2 TORNADO

TORNADO is a concept formed on the basis of the Horizon 2020 projects STORM (STORM, n. d.) and TEMPO (TEMPO 2017 c) and stands for 'Temperature Optimization to Revive Networks by Add-On Technology' (Vanhoudt & Johansson, 2019). The project idea was presented by the Belgian research institute VITO and with technology developed by NODA and Elvaco, Sweden. TORNADO will form an add-on platform to existing DH network and substation control systems, consisting of both hardware and software. The aim is to automatically detect, analyse and correct faults in user district heating substations and buildings using meter data. The TORNADO process includes three steps: fault detection (to identify the worst performing substations), fault diagnosis (to identify why they are not working sufficiently) and fault correction (to conclude how this can be fixed). In addition to this process, which aims to increase the cooling in the substations and reducing the return temperature and thus allowing for a reduced supply temperature, the TORNADO solutions include knowledge transfer to customers, hopefully increasing the incentives to keep a well-functioning substation.

If installed in a district heating network, TORNADO is implemented and run via several iteration steps, described below:

1. Understanding the grid using historical data
2. Integrating with the grid using meter data – hourly data from the heat meters are required.
3. Measuring the normal operation of the grid, forming the baseline status.
4. Analysing the grid using customer data and ranking the worst performing substations.
5. Initiating a dialogue with the customers with the worst performing substations, finding incentives to adjust the issues.
6. Gather more detailed data and information from badly performing substations and secondary systems to find the right measures to reduce the return temperature.
7. Lower the supply temperature, maintain the dialogue with the customers, quantify the benefits and continue the iteration process.

3.4.3 NODA

The heat load in district heating systems of today typically varies with the time of the day, as it follows not only the outdoor temperature but the customers' use of domestic hot water as well. On weekdays, this typically results in two distinct peak loads during the day – one in the morning and one in the late afternoon/evening. These peak loads are often costly for the DH companies, as peak load boilers might have to be started and as it results in an uneven heat production, reducing the efficiency of the baseline heat plants. Nowadays, however, it is possible to reduce these peak loads and "smoothen out" the energy consumption over a longer period by using substation data and by calculating and managing energy storage capacity in the buildings (NODA, 2019). The fundamental idea is to utilize the inertia in the (larger) buildings connected to the grid as a sort of a secondary buffer system – which can be loaded with energy when there is surplus production available (e.g. during night time) and unloaded at peak load periods to even out the production. The effect on the indoor temperature is quite small due to the heat stored in the very construction of the buildings. However, this procedure needs to be accepted by the owners of the relevant buildings, and a small fluctuation of the indoor temperature may be experienced. If a sufficient number of buildings in the grid is connected to a smart heat load control system, the output is that the load in the grid can be controlled to a certain extent. One company, amongst others, that offers such system is the Swedish company Noda. Their product on the market is called Noda Smart Heat Grid (NODA, n. y.).

Noda Smart Heat Grid uses an algorithm that takes in data from measurement points in apartments, outdoor temperature and weather forecasts to optimize the energy use in customer substations (Bergmark, M. & Näslund, M., 2019). The previously mentioned thermal inertia in the building can be used to avoid peak loads in the gird. The same algorithm accounts for the production conditions in the district heating system (NODA, 2019) and makes evaluations and analyses of the situation, leading to automated decisions regarding both heat production and consumption. These three steps – measuring, analysing and controlling – is iterated in a continuous cycle to balance the energy consumption at the customers and the energy production at the heat plants (NODA, n. y.).

In addition to controlling the heat production and reducing the peak load in the district heating grid, Noda Smart Heat Grid also enables district heating companies to avoid bottlenecks in the grid. Areas located far from the production site(s) may sometimes experience problems with the distribution of pressure and/or flow. By applying Noda Smart Heat Grid to the buildings in such areas, the peak loads, and thereby peak flows, can be reduced and an even distribution of energy can be achieved. Furthermore, it potentially allows for new connections in these areas, where normally a new distribution pipe would have been required.

Using customer data and real-time measurements together with weather and load forecasts to reduce the peak loads in DH grids allows the district heating companies to avoid using expensive peak and/or reserve heat production, thus reducing the production costs. This will in the long term reflect to the customers in shape of lower heat prices. Last but not least, it is a solution that is environmental friendly, as peak heat production often is based on fossil fuels (NODA, n. y).

3.4.4 ngenic

Ngenic is a product that is marketed as a smart thermostat. The main customer segment is single family houses or detached houses. Ngenic consist of indoor temperature sensors, a gateway and a control box. The gateway receives all information and communicates with cloud based algorithms which calculates parameters and return them to the gateway and controller for an optimized energy and comfort performance. The installation of ngenic to district heating substations is quite simple; the signals from the outdoor temperature sensor to the traditional controller is interrupted and replaced by the ngenic control box. For the customer ngenic offers remote settings for desired indoor temperature and improved control of the settings for the heating system and reduced district heating return temperature. For the DH companies ngenic enables remote demand side management for connected customers. (ngenic, n.d. a; ngenic, n.d. b; ngenic, n.d. c).

4 Leak detection or assessment of service pipes by using meter reading

To use district heating meter readings for condition monitoring of insulation status in the DH service pipes is a scope mentioned in the COOL DH application. This chapter describes a method for detecting damages in service pipes through analysis of customer meter readings. The study is based on a backwards theoretical reasoning on how much damage must be caused in the insulation of a service pipe in order to be detected as an anomaly in measurement data. A full description of calculations used in this theoretical reasoning can be found in Appendix B.

4.1 Motivation of study

Standard PUR isolated district heating pipes are often equipped with alarm wires used for leak detection. However, flexible service pipes often lack alarm wires and can therefore not be monitored as the rest of the network. When it comes to plastic district heating pipes currently on the market, they all lack possibility for surveillance of leaks (however in COOL DH such pipes with surveillance will be developed). In general, leaks can be divided into two different categories: 1) damaged casing and 2) pipe damage causing leakages of district heating water into the insulation, see Figure 3.

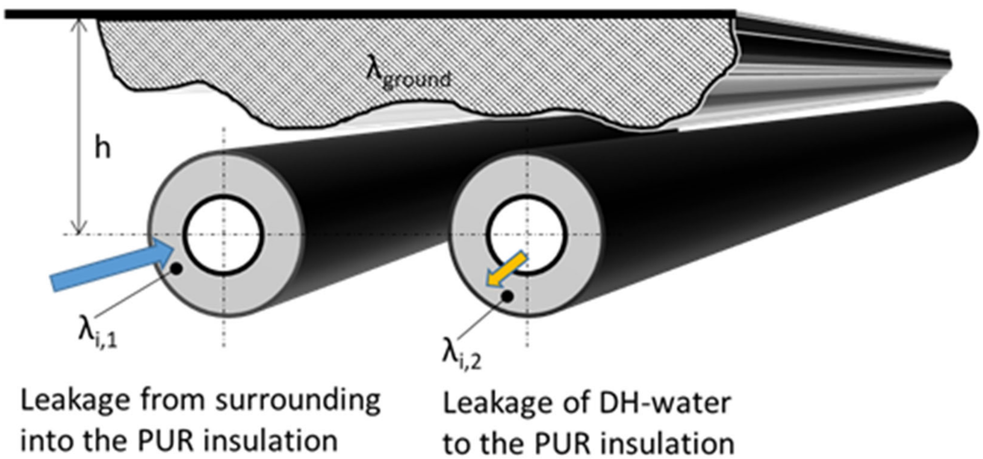

Figure 3. Principle of leaks. 1) from surrounding through the casing and into the insulation. 2) Pipe damage casing DH water to enter the insulation.

Damages in casing is the most common cause of leaks and particularly faults in casing joints. A damaged casing allows water to enter the insulation and thereby reduces the performance of the insulation which causes the heat losses to increase. In the longer run, the damped PUR insulation may cause corrosion and eventually cause leakages of district heating water.

The scope of this subproject is to find out if the existing measurement data collected via heat meters could be used for condition monitoring of insulation in the DH network's service pipes. The basic idea is to evaluate if changes in heat losses due to damaged pipe insulation can be detected by meter readings of temperature or flow at the customer. The scope only covers analysis of conditions in the supply service pipes, not return pipes.

4.2 Cases

Calculations are presented for two cases; outside heating season and during heating season. For the calculations stable heat load and DH district heating temperatures are essential. The case outside heating season is chosen due to low and stable flow conditions through the heat exchanger that occurs night-time when only bypass flow through the heat exchanger is present. The case during heating season is calculated for a stable heat load of 100%, 75% and 50% of the assumed dimensioned space heating demand.

The calculations are performed for a detached house with a 20 m service pipe, 20/90 steel flex. For a principle illustration, see Figure 4. A full description of theory, methods and results from the calculations is presented in Appendix B.

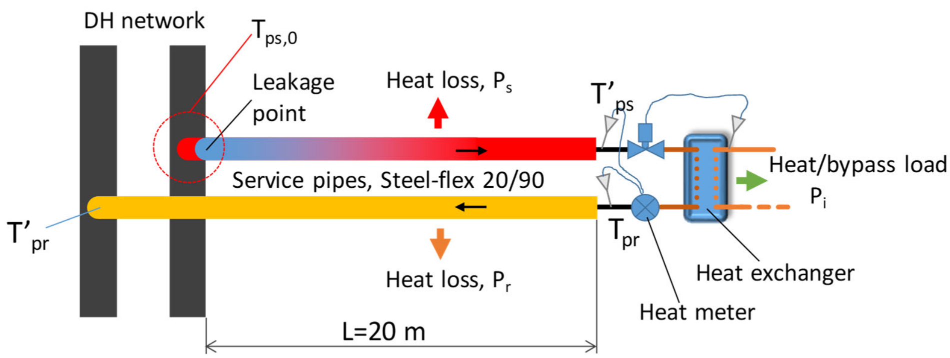

Figure 4. Service pipes connecting a DH substation to DH network.

The calculations are performed with damaged insulation at the starting point of the service pipe, see leakage point in Figure 4. The water content in the insulation at the point of leakage has been varied from 7 to 99% and is compared to a reference case with 0% water content. The water content is declining to 0% after 10 meters. A water content of 6-7% is the maximum amount of water that the PUR insulation can hold *if not damaged* (Cai, S., 2014 et al.; Endres, E. & Kleser, J., 2008). However, if the PUR insulation is damaged, which may be the case if district heating water is allowed into the insulation with high pressure and temperature, the PUR isolation may hold a higher concentration of water. The temperature in the district heating network at the beginning of the service pipe, $T_{ps,0}$ is assumed to be known and is, in the calculations, fixed to either 90°C or 65°C.

4.3 Results

4.3.1 outside heating season

The computation case outside heating season is performed as a night-time case when the probability for DHW consumption is low and stable flow and primary temperatures can be assumed. The only heat load is heat losses in the substation due to bypass flow which is dimensioned according to well performing substations with proper tap water regulation with a heat loss of 100 W and corresponding flow rate of 0.002 l/s and set point for T'_{ps}=55°C [10]. Results

[10] Data based on compilation of results for district heating substations fulfilling P-märkning. Data available from RISE, http://publiccert.extweb.sp.se/sv/Product/List/1086 [2019-03-15]

from the calculations show an increase of mass flow through the substation due to the increased heat losses even though the impact is low, see Table 4. When comparing the results from an undamaged pipe, the mass flow increases from around 7.3 l/h to 9.2 l/h if the water content is 80% at the point of leakage. When water concentration is 99%, the flow rate increases even further. A water content of 7%, which would be the normal maximum water content without damage in the PUR insolation, the change in mass flow is neglectable.

Table 4. Results from the summer case with Ts = 65°C. Δm indicates impact on flow-rate through the heat exchanger in case of damaged service pipe. ΔT_{ps} is constant here, 10°C.

Water content	m	$T_{ps,0}$	T'_{ps}	T_{pr}	T'_{pr}	$Q_{loss, supply}$	$Q_{loss, return}$	Δm
%	l/h	°C	°C	°C	°C	W	W	l/h
0	**7.28**	**65.00**	**55.00**	**40.67**	**35.35**	**84.8**	**45.1**	
7%	7.54	65.00	55.00	41.06	35.82	87.7	45.9	0.3
80%	9.20	65.00	55.00	43.15	38.46	107.0	50.2	1.9
99%	14.79	65.00	55.00	47.13	43.73	172.1	58.5	7.5

In Figure 5 the DH temperature in the service pipe is illustrated. In the figure the mass flow corresponding to a water content of 0%, 80% and 99% is also shown.

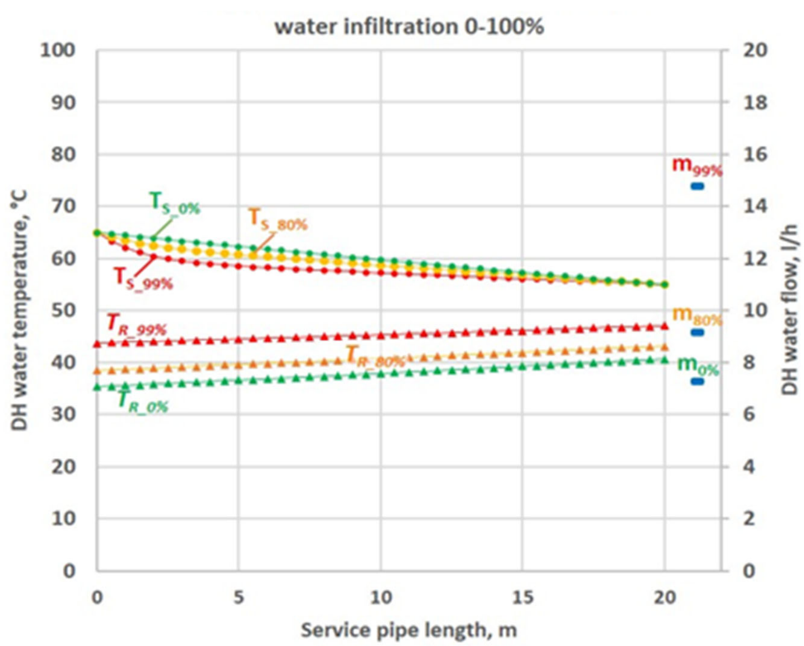

Figure 5. Temperature drop in service pipe and corresponding flow rate for water infiltration 0-100%. T_s=65°C, T_{DHW}=55°C

Detecting changes in flow through the heat exchanger due to impaired insulation in the service pipe is difficult since the actual flow change is too low. To detect changes in flow rate, a change of the flow through the heat exchanger of

10 l/h is needed with the current standard for meter readings. Even with higher resolution from heat meters, this method for leak detection is not very feasible since it requires stable conditions in terms of heat load and primary supply temperature.

4.3.2 During heating season

The cases calculated that correspond to conditions for the heating season are based on the case described in section 4.2 but now the heat load from a bypass flow is replaced with a space heating system dimensioned for 9 kW and 60/40°C radiator program. Calculations of heat losses in service pipes with a water content at point of leakage between 7 and 99% were performed for space heating loads of 9 kW, 6.75 kW and 4.5 kW. All calculations were performed with a stable supply temperature at the branch. The heat demand was assumed to be constant and no demand for domestic hot water was considered. Results show that a water content of 7 % at the point of leakage results in less than 0.01°C decreased supply temperature at the district heating substation, see Table 5. If the PUR insulation is damaged and the water content is 99 % at point of leakage the increased temperature drop in the supply pipe will be >0.75°C compared to reference case with 0% water content. Even if this would be detectable it requires known and stable temperatures at the branch.

Table 5. Results from calculations with heat load for space heating. T_{ps} = 95°C. at the branch and T'_{ps} when entering the heat exchanger. ΔT_{ps} indicates impact on the temperature drop in the supply service pipe due to damaged service pipe. Δm indicates impact mass-flow through the heat exchanger in case of damaged service pipe.

Heat load	Water content	m	$T_{ps,0}$	T'_{ps}	Heating system		T_{pr}	T'_{pr}	$Q_{loss, supply}$	$Q_{loss, return}$	ΔT_{ps}	Δm
kW	%	l/h	°C	°C	T_s (°C)	T_r (°C)	°C	°C	W	W	°C	l/h
9	0	160.9	90.0	89.3	60.0	40.0	41.2	40.9	137.3	49.8		
9	7%	160.9	90.0	89.3	60.0	40.0	41.2	40.9	138.0	49.8	<0.01	<0.01
9	99%	163.1	90.0	88.5	60.0	40.0	41.1	40.9	281.0	49.6	0.75	2.16
6.75	0	115.6	90.0	89.0	51.6	36.6	38.9	38.5	136.9	45.5		
6.75	7%	115.6	90.0	89.0	51.6	36.6	38.9	38.5	137.6	45.5	0.01	<0.01
6.75	99%	118.1	90.0	87.9	51.6	36.6	38.8	38.5	281.1	45.5	1.03	2.52
4.5	0	73.1	90.0	88.4	42.8	32.8	35.5	35.0	136.6	39.5		
4.5	7%	73.1	90.0	88.4	42.8	32.8	35.5	35.0	137.3	39.5	0.01	<0.01
4.5	99%	75.2	90.0	86.8	42.8	32.8	35.4	35.0	279.6	39.4	1.59	2.16

4.4 Discussion and findings

The impact on temperature drop and corresponding changes in flow rate due to damaged district heating service pipes is relatively small. To be able to detect these small changes, stable conditions are required, both in terms of heat load and supply temperature at the branch. Even though the heat losses increase it will only result in minor changes in flow rate through the heat exchanger in a summer case, outside heating season. Even leakages resulting in damaged PUR-insulation and extreme high water content would be hard to detect with regular data from district heating meters. During the heating season, with a stable heat load, the increased heat loss in the service pipe results in a reduced supply temperature at the district heating substation. The impact on the supply temperature is moderate and to be able to detect this minor change, the temperature at the branch needs to be known and the conditions needs to be stable. In a district heating network, the supply temperature is not known at all points, and if it is known, the resolution may be too low.

The conclusion is that the described analysis method is not showing satisfactory results in order to be used as a method for finding leakages in service pipes. Also, even if it would be possible to detect leakages in service pipes by using the energy meter as suggested, it would still only cover potential leakages in the supply pipe since the return temperature that from the district heating installation at the branch is unknown and not measured.

5 Conclusions

Regulations on metering and state of art of metering systems in Sweden and Denmark

In Sweden, there are requirements for monthly readings and billing of district heating customers since 2015, which has led to remote readings now being a standard. The same requirements have not been introduced in Denmark, but it can be concluded through a study made by EWII, Grøn Energi and Transistion, that the heat meters used today in Denmark nevertheless seems to meet the requirements for remote reading. The problem is hence not the heat meters, but the data communication systems. About two fifth of the Danish district heating companies, according to the study, will have to upgrade their systems to meet the requirements for remote reading that the EU sets to 2020 for new installations and 2027 for meter changes.

The Energy Efficiency Directive as from 2012 and supplemented in 2018, requires individual metering and charging (IMC) in multifamily houses which means that every household would have to pay for their own consumption of heat and hot water. In Denmark, there has been a long tradition of IMC, which does not find any equivalent in Sweden. There is a loop hole in the directive that involves cost-efficiency. In Sweden, the Swedish National Board of Housing, Building and Planning has come to the conclusion that it cannot be considered cost-effective to install IMC for the Swedish case, neither in existing houses nor in new constructions. In Denmark, requirements have been introduced for IMC in the Building Act.

The central European perspective on IMC that emphasizes the importance of IMC as a way to strengthen households' room for maneuverer and incentives to save money and energy, has been questioned from Sweden and other Nordic countries. The objections raised are the following: the incentives to make energy efficiency measures in the building envelope decrease for the landlord; it becomes more difficult to introduce and use more complex price models for district heating to household customers than for larger property owners; the management of IMC leads to increased administrative costs; and that IMC in fact can introduce problems with energy poverty that do not exist today in Sweden because the heat is included in the rent for the tenants.

The different requirements of individual metering and charging in Sweden and Denmark may affect the countries interest for installation of individual district heating substations at each household in low temperature district heating grids. By installing flat stations, the requirement of IMC will automatically be met, but in Sweden the requirements for IMC is not enforced in Swedish legislation which means that this incitement is not valid for the Swedish case.

Price models and charging of heat are driving the development of metering systems

The requirements for the quality of the measured values from heat metering are today set based on charging purposes. In other words, this is what drives development and requirements for the measuring systems today.

According to the regulations, the customer must be charged according to actual consumption, that is, the customer must not pay according to standard or annual settlement, but only by measured values. The lowest time resolution according to the law in Sweden is daily values for the energy consumption and other load-based measurement values. If a price component with a higher time resolution than day is applied in the price model, these measured values should be reported to the customer. Load components based on hourly load will stress the demands on the energy meter setting so that hourly level data can be obtained. Flow components based on return temperature also need to be based on hourly values.

Studies show that there is an increased interest in introducing more complex price models for district heating, especially in Sweden. The district heating companies want the price models to better reflect on production costs and distribution costs in order to lower financial risks. Incentive based price components like load components and flow or return temperature components are introduced as means to affect consumption behaviour and customer interest of maintenance of the district heating substations.

Functional requirements on heat meters and communication systems

Important functional requirements of meters and communication systems have been identified by studying information from manufacturers or retail companies of heat meters, consultant companies and information compiled by authorities. The functionalities that were found could be categorised in four categories; technical functionality, security and personal integrity, analytic requirements and requirements ensuring business development.

When choosing meters and communications systems, technical issues like communication range, dependency of other networks and immunity from interference from other devices should be considered.

Aspects of security and personal integrity should be considered where solutions that can help avoiding risks of measurement data being manipulated, unauthorized persons getting access to data and control of switches should be considered (such as data encryption, role-based access to data, logging of activity, multiple security layers and contingency plans).

As for analytic requirements this study has given several examples of different applications where customer data have been used as bases for analysis. Examples of applications for planning and operation of the district heating system identified in various research projects are the following:

- Fault detection of district heating substations and pipes
- Fault diagnosis of district heating substations
- Load prediction
- Prediction of behaviour of prosumers in the district heating grid
- Demand response – information on customers' behaviour and customer appliances

An outlook in this report has also been made for applications from data analysis on meter readings in the electricity industry, where additional areas of analysis have been identified that might be transferable to the district heating industry. One such area of interest is to use the customer data to measure the quality of the deliverance of heat, for example by:

- Looking at supply temperature and differential pressure at the customer
- Making prediction of how long time the customer will sufficiently be provided with heat during outages in the district heating system

We have not been able to find these kind of applications for district heating in research reports. This might be explained by the fact that today, there is no functional requirement for district heating set in any law and there is also no industry-wide definition of a district heating outage/interruption. There is, however, an ongoing discussion between the Swedish Energy Agency and the Swedish District Heating Association (Swede Energy) on security of supply for district heating and how disruptions in deliveries should be defined. Depending on what comes up in this work, new requirements for following up on security of supply or power quality can influence which analyses can be interesting and suitable to do using data from customer meter readings.

As for requirements ensuring business development, two specific areas have been identified to be important to think about when deciding on requirements for heat meters and communication systems. The first area is the possibility to offer customers access to their own energy consumption locally, so that the customer can use the data for their own analyses and energy management systems. The second area is the possibility to develop price models that can influence customer behaviour. For the customers, to get local access to meter values a digital interface to home/customer facility is needed, for example an M-bus interface. The communication solution should also support a future standard for communication with devices in the home. The requirements for the heat supplier today is to provide data on consumption per day, week, month and year for a period that includes at least the last two years or the current delivery contract term. This applies to all billing values, which mostly means values for energy use, if not incentive based price components are introduced to affect peak load behaviour or the cooling in the customer district heating substation and internal heating system.

Requirements on data frequency and additional measurements at the customer side

The introduction of AMR, that can provide high resolution of measurement data for district heating consumption, has happened quite recently. The development in Sweden has been faster than in Denmark due to the legal requirement that came in 2015 for monthly charging of district heating based on read values, now making the use of metering systems that can handle at least hourly values a standard. The research on data analyses using measured values from customer data has thus come to light in recent years and is still in its infancy. Consequently, the research has not yet come far enough (in terms of the use of measurement data for analysis using for example machine learning, artificial intelligence and statistical methods) to be able to say which resolution of measurement data would be suitable for analysis, or which other data would have to be included.

There is an implied idea that a more high-resolution measurement data could open for better data analysis. However, this must be put in relation to the number of measurement values which increase exponentially with the time resolution. To constantly handle this vast amount of data takes a lot of resources, both at collection and data storage. Also the meters have limited battery capacity which will not last 10 years if sampling frequency is increased over longer periods.

Experiences from the projects presented in this report show that hourly meter readings seem to be sufficient for autonomous data analysis in order to identify poor functioning district heating installations and to make accurate load predictions. Some research projects have also shown that methods for forecasting and categorization of customers based on data analysis of meter readings have been successfully developed. Both forecasting and categorization can be of great benefit to future fault identification. Moving on from fault detection to fault diagnosis, a higher resolution on meter readings may be necessary. The possibility of changing the resolution of the measurement for specific periods needed for analysis can, however, be a viable way to handle the need for data with higher resolution.

Secondary meter values from the customer installations would be beneficial for developing algorithms for fault detection and improved performance of the district heating system, for example indoor temperatures and secondary temperatures measured on branches for heating system within the building. Measurement of district heating differential pressure at the customer was an input mentioned by manufacturers of district heating substations when asked about new requirements for data. Measuring the differential pressure over the customer installation would make it possible to estimate performance of the district heating substation and the control valves.

Increased measurement of secondary parameters in the customer's facility to find, by use of AI, the relationship between how secondary conditions (conditions at the customer installation) affect the primary district heating system, is an interesting development for further research. Finding these relationships would make it possible to assess or assume secondary phenomena through analysis of primary data.

More research is needed to increase the knowledge regarding the potential for different methods of fault diagnosis, load prediction and customer categorization. The problem today is not the data processing itself, but rather that there is not enough marked data where different algorithms can be tested. There is a need for higher resolution during the development phase of algorithms for automated diagnosis and optimization of district heating systems. To develop new products for optimizing district heating systems, an expanded test bed and database where extended data and information from a number of different customer installations, from a number of different district heating systems and from a number of different countries would be of great use.

Theoretical study on using meter reading to detect heat losses in service pipes

One scope within this project was to evaluate the feasibility for usage of meter readings from customer installations to detect increased heat losses in service pipes due to the intrusion of moisture.

Results from the theoretical study carried out showed that even though the heat loss in the service pipe increases due to moisture content, the impact on the measured parameters of temperature and flow is low and would be hard to detect. A higher resolution of meter readings would not improve the feasibility to use meter readings for monitoring increased heat losses in service pipes since, if feasible, it would require stable heat load at the customer and stable and known temperature conditions in the district heating network.

Studies of how district heating companies in Denmark and Sweden work with cooling

Through studies performed within this work and by other researchers (surveys and interviews) it is clear that district heating utilities, both in Denmark and Sweden, acknowledge the matter of good cooling in the district heating grids to be an important issue to work with. A key factor for success within this field is good customer relations and access to the customer's district heating substation. This may be a driving force for district heating utilities to offer service agreement and ICT-platforms for greater customer engagement. Customers seem to be more willing to take actions to improve their installations if they understand why this is important. Having the analytic tools for finding the customers with malfunctioning substations or malfunctioning internal heating systems is not enough to solve the problems with bad cooling. A good business model, that ensures access to the customer installations and that enhance customer interest keeping the return temperature as low as possible, is equally important.

Recommendations

The following recommendations are given based on the overall picture provided by the report's different compilations and studies:

- The meter should be able to measure the energy for every hour and be able to convert to measure with higher frequencies (minutes). Some types of measurement data analyses may require a higher resolution than hourly measurement, which is why the possibility of higher resolution should be provided, without that being a default setting.
- It should be possible to remotely upgrading the meters and to remotely change the meter frequency. This will provide that new functionalities can be introduced in a cost-efficient way and that expensive field visits can be avoided.
- Access to secondary meter readings. The following measurements are seen as the most important: Indoor temperatures, secondary temperatures measured on branches for the heating system in the building, and measurement on the district heating differential pressure. Measuring these parameters would be beneficial for developing algorithms for fault detection and for improving system performance for the total district heating system, as well as for as being able to guarantee the quality of energy supplies at the customer substations.

- There should be a digital interface that the end customers can use to access their energy consumption locally. The communication solution should also support a future standard for communication with devices in the home. In order to be of real use for the customers, this should be delivered with some kind of analysis tools that can help the customers relate their consumption or data to reference data (for example historical data, norms or set point values) and that can provide the customer with extended analysis that make sense to the customer.

COOL DH
COOL DISTRICT HEATING

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Appendix A

Survey to Danish district heating companies about strategies to work with cooling in district heating grids

Background

1. Please state the company name, your name and what your role is at the company.

2. What are the average temperature levels in your DH-system?

- Supply:

- Return

3. Are you satisfied with the cooling (delta T), i.e. the difference between supply and return temperature, in your network?

- Yes, the cooling is sufficient.

- We are somewhat satisfied with the cooling but there is room for improvement.

- No, significant improvement is required.

4. Who owns the substations located at the customers in your network.

-The company.

- The customers themselves.

- Other______________________

5. Customer data collection

- How do you collect customer data for billing?

    - Automatic collection.

    - Manual collection.

- Which values do you collect?

    - Energy (kWh).

    - Flow (m^3).

    -Temperature of the supply feed to the substation.

    - Temperature of the return feed from the substation.

- At what time interval is data registered?

  - Every 30 minutes (or less).
  - Hourly.
  - Daily.
  - Other____________________

- How often do you collect the data? ______________________

5. Flow fee

- In your price model, do you charge for the flow of water through the customer substation?

  -Yes.
  - No.

- If yes, could you briefly describe the price model and the flow component?

6. Service agreement

- Do you offer service agreements to your customers?

  - Yes.
  - No.

- If yes, what is included in such an agreement, what percentage of customers have service agreements and are they mostly private or corporate customers?____________________

Efforts to improve cooling/reduce return temperature

7. Based on your company's vision, what would you say are the primary incentives to reduce the return temperatures? Please rank from most important to least importan (1-3)

- To increase the efficiency of our production (Lower return temperature provide improved efficiency for flue gas condensation and/or heat pumps.)

- Reduced heat losses in the distribution network.

- Increased opportunities to connect new customers to the DH network.

- Other_______________

8. Are you currently working actively to reduce the return temperatures from the customer sustations?

- Yes.

-No.

9. If you are working actively, how do you work with the customer to reduce the return temperatures from the customer substations?

- How do you find customers with poor cooling/high return temperatures?

  - Manual search and analysis.

  - We use customer data and computer analysis.

  - We discover mal-functioning substations during service visits.

  - Other________________

- Comment______________________________

10. When customers with poor cooling/high return temperatures have been identified, how do you proceed? (contact the customer, service/maintenance included?)

____

____

Any other comments?

Appendix B

Leakage detection in service pipes to detached houses by using standard meter readings

Janusz Wollerstrand
Per-Olof Johansson Kallioniemi

Energy Sciences
FACULTY OF ENGINEERING, LTH
Lund University

April 2019

Introduction

Measurement data is collected in DH-systems on several levels. In the SCADA system in DH networks- for operational monitoring, in the connected customers' heat meters- for billing and in the district heating substations' control equipment and for possible optimization and diagnosis. The availability of data sets that is constantly increasing and the traditional boundaries between billing systems and network monitoring systems are unravelled.

The scope of this subproject is to find out if the existing measurement data collected via heat meters could be used for condition monitoring of insulation in the DH network's service pipes, which often lacks alarm wires and are therefore not monitored in the same way as the main lines and distribution lines of the network. This is done by a theoretical reasoning as to whether an injury in the insulation affects the heat losses sufficiently in the short distance that a service pipe constitutes, that it can be detected in measurement data and distinguished from measurement inaccuracies present in the measurement of flow and temperature.

The established way of detecting impaired insulation in district heating pipes is by using alarm wires, which signals moisture in insulation and is usually incorporated in continuous operation monitoring, or flight thermography of the ground surface to detect heat leaks, which can be done during the year's cold period. The latter has become so cheap that many district heating companies nowadays do it annually.

There are some ongoing research on methods for identifying leaks in DH networks based on measurement data retrieved from existing SCADA systems through calculations. According to a recent review of Zhou [1], these methods are still too uncertain, much because of the quality of measured values, insufficient number of measuring sensors and lack of knowledge of where in the network sensors must be placed to provide a reliable picture of the network's state of leakages. Zhou et al. also highlights that thermography at present time lacks computer support for automatic analysis of images and identification of suspected leakage points. Thus, minor leaks can be difficult to find. Ekroth [2] notes, however, that with respect to thermography, there are already additions to certain GIS software, which find potential leaks automatically. These programs can be supplemented with additions that sort out disturbing image components that can generate false alarms, eg vegetation that has been heated by the sun during the day. Both references state that thermography has a great development potential.

The fact that the insulation properties of the district heating pipes deteriorate is sometimes due to purely mechanical damage, typically during excavation, but the most common reason is that insulation becomes moist, which decreases the insulation's total heat conduction resistance. The moisture initially enters from the outside, in the form of groundwater or storm water, through holes caused by mechanical damage on the pipe's protective casing, or by leaks in casing joints. This is a relatively slow process and it does not, as we will show with a simple calculation, lead to a noticeable increase in heat losses in the short term. However, there is a great risk that increased moisture content in insulation will lead to corrosion and penetration of the media pipe surface (applies to steel pipes), which eventually leads to smaller and then increasing leakage of district heating water. Although the district heating water initially stays in the insulation, the warm district heating water has a much greater ability to degrade the insulation capacity than seeping groundwater would, due to significantly higher pressure and temperature.

Here we focus on the most common insulation material in district heating pipes - PUR foam. The PUR foam consists of polymers and of substantially closed cells filled with gas. The volume ratio of polymers in PUR foam is just over 3%. So even if the water leaks into the foam, under normal conditions it cannot fill all the voids in the insulation and expel the gas. The voids that are not closed are estimated to be 6-7% of the volume of the foam and hence only an equal volume of water can leak in [3, 4]. In addition, the water cannot propagate freely along the conduit without any apparent driving force (pressure gradient). Therefore, the proportion of the water in the insulation decreases with increasing distance from the place where the casing / casing joint is undamaged. It can therefore be assumed that, as long as it is an external damage with leakage of ground water, the moisture does not spread significantly in the insulation.

The situation changes as the district heating water starts to leak. The insulation will now be filled with water with a higher pressure and temperature. The critical point is the welding joints between pipe sections, where the PUR foam is injected into the void between the sections only after welding out in the field. Since the injected foam does not have the same quality as the prefabricated, it can be softened and also "mashed" by the hot water jet of the leak. In an extreme case, that part of the volume of the insulation is almost completely filled with water, which means that the heat conduction increases approximately 20 times. In addition, the water has now higher ability to spread further in the insulation, up to 10 m from the damaged site.

The above reasoning is based on practical considerations based on information we have been able to collect during the relatively short time of the project. Specific information on how water damage affects insulation and its thermal insulation capacity in district heating pipes is very difficult to find in the literature. We have asked the question to district heating pipe manufacturers without receiving satisfactory answers. The laboratory tests that we have been able to find, relate to PUR insulation intended for buildings, above and below ground, and thus have a different focus. We have also been in contact with district heating companies and found that even if there is a good preparedness for leaks to occur, there are no routines for following up how damaged the insulation has become in the pipes that has been replaced. However, we have got information that the need to replace several meters of pipe in case of leakage because the insulation has been damaged by moisture, is not unusual [5].

A unique example of reports regarding moisture impact on insulation of DH pipes was performed at the Danish Technological Institute on behalf of the Danish district heating association [6], where moisture content in older district heating lines that have been in operation for 10-20 years was investigated. Unfortunately, the project are not about steel pipes, but about PEX pipes without diffusion barrier. However, it is relevant to see how much moisture that can penetrate into PUR foam insulation and how much the foam's thermal conductivity increases because of it. The project found, among other things, that the water content of PUR foam could be significantly higher than 7% in the event of heavy leakage and when the foam was exposed to water diffusion from PEX pipes for many years.

Main idea

In order to calculate heat loss in a service pipe, you need to know the flow through it and the temperature drop. The difficulty is that you do not know the incoming temperature to the service pipe because the number of temperature sensors in distribution lines are very limited. One could use temperature from the nearest transducer or a temperature calculated using a simulation model of the network, but then an unknown uncertainty is introduced in the calculation. Furthermore, flow measurement must be sufficiently accurate to detect altered heat loss if leakage occurs in the service pipe. The flow at the measuring point must furthermore be stable to minimize the influence of the heat inertia of the pipes.

In order to minimize the impact of other factors, we have chosen to focus on the operating situation at night during the summer months. We calculate on the one hand what flows occur in the service pipes in small-house areas and on the other hand we analyse the measurement data provided by a district heating company.

The aim is to check whether it is realistic to try to detect damage caused by damp / deterioration of isolation in serviced pipes to small houses by analysing measurement data available through the district heating company's heat metering system, especially flow and temperature variations.

We have identified a limiting factor - the technical properties and configuration of the heat meters (which may vary depending on the owner's preferences). Heat meters are designed to measure and record the forward and return temperatures of the district heating water and the flow volume. Based on these values, the temperature difference between the forward and return flow is then calculated, as well as the energy consumption and the instantaneous flow and power. The values are usually stored once per hour and transferred to the district heating company's billing system. The temperature difference is recorded as degrees with two decimals, but the temperatures themselves are sometimes only recorded as whole degrees, depending on the settings. Remaining registration depends on the size of the meter. For small meters, it is typical that the flow volume is recorded in m^3 with two decimals, which corresponds to 10 litres' resolution, and the energy - in MWh with three decimals. Furthermore, the instantaneous flow is recorded in whole l/h and the instantaneous power in kW with one decimal [7]. That the flow is recorded in l/h means that if the flow changes by e.g. 5 l/h then this change has a numerical inaccuracy +/- 10% (the actually measured value is in the range 4.5-5.5 l/h). In other words, the heating flow must vary 5 l/h or more if the variations shall be accepted as an input value to reliable diagnosis.

In addition to the calculations performed for summer conditions, calculations of temperature drop in the supply service pipe has been performed for three different heat loads which corresponds to the conditions that exist for the heating season.

Heat loss calculations

Our calculations apply to a district heating substation in a small house, connected to the district heating network with a 20 m long service pipe consisting of two separate lines (DN 20), see Figure 1, one supply pipe and one return pipe. The picture of the substation in the figure includes domestic hot water heat exchanger and control valve, as well as heat meter only. Other equipment is omitted to simplify the picture.

Heat loss in the service pipe is calculated using formulas obtained from [9]. Initially, we assume a summer case, time interval at night when there is neither radiator load nor DHW tappings. There is then a heat holding flow generated by the tap water circuit's self-acting control valve. After studying a set of results achieved from tests for certification of DH substations (so called P-marking) [7], we have chosen two different set points for the incoming DH-water temperature at the substation, T_{DHW}, 50 and 55°C respectively. Furthermore, we have chosen the temperature of the district heating water in the distribution line that the service pipe is connected to, T_s, as 65 and 90°C, respectively, where 65°C is more relevant for a summer case.

The size of the heat retaining flow is thus computed, based on selected T_s and T_{DHW} and the heat loss of the service pipe, P_s. In a real district heating substation, the DH-water flow through DHW-heat exchanger is controlled by a control valve, which, when a hot water outlet ends, shuts the flow off. However, after some time, when the water around the valve's temperature sensor starts to cool, the valve opens slightly again, enough to keep the temperature of sensor at the set point temperature.

The return temperature from DH substation, T_r, is calculated taking into account the heat loss at idle in the substation itself, P_i, which we have set to 120 W based on the certification tests mentioned above. Note that the idle heat loss occurs to ambient air in the FC room and that it drops with descending T_s. Thus, the temperature T_r is lower than T_s, but can never be lower than the selected ambient temperature. Finally, the heat loss in the return pipe, P_r, depends on what T_r becomes. The calculation is iterative and is performed using the Matlab® software.

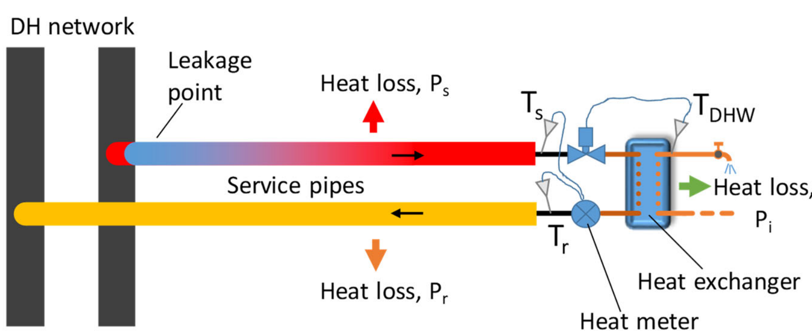
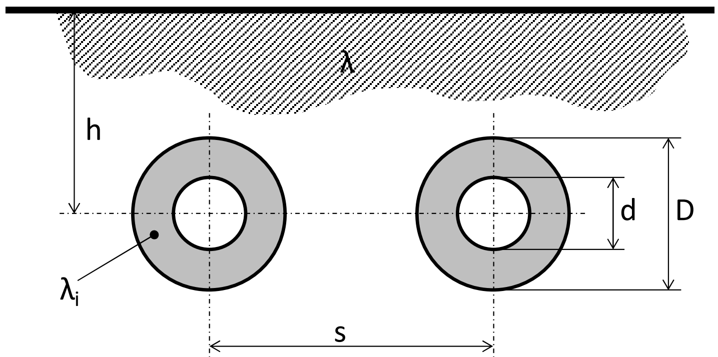


Figure 1. Service pipes connecting a DH substation to DH network. Only domestic tap water heat exchanger of the substation is shown in the figure.

Figure 2 shows the location of the service pipes under the ground and the values assumed for calculating their respective heat loss. The dimensions of the pipes and the thermal conductivity coefficient of the insulation are taken from Logstor A/S product catalogue 2018.02, section 3.4.2.1 "Steelflex pipe", component no. 2100, d = 20 mm.



λ = 1.50 W/m,K	- thermal conductivity in the ground
λ_i= 0.022 W/m,K	- thermal conductivity of the insulation
h = 0.6 m	- distance from the ground surface to the centre axis of the pipe
s = 0.3 m	- distance between centre axis of the supply and return pipe
d = 20 mm	- outer diameter of the pipe (pipe wall thickness 2.0 mm)
D = 90 mm	- outer diameter of the protecting casing (wall thickness 2.5 mm)
T_a = 12°C	- mean temperature of ambient air at the surface of the ground

Figure 2. Sketch of preinsulated DH pipes buried in the ground with dimensions and heat coefficients indicated.

For each combination of T_s and T_{vv}, heat losses for the both service pipes and for the DH substation have been calculated in five cases: one where the insulation is in perfect condition, followed by four other where the insulation contains 7% water (by volume) on a distance of 0.5, 1.0, 5.0 and 10.0 m respectively, measured from the connecting point of the service pipe to the DH network (see blue marking on the supply pipe in Figure 1).

The heat loss calculations during heating season are all performed with an assumed primary supply temperature at 95°C. The calculations are performed for three different heat loads corresponding to 100%, 75% and 50% of the assumed dimensioned heat load, 9 kW. The space heating temperature program is assumed to follow a standard 60/40°C program (see for example [10]). The DH-return temperature and corresponding mass flow through the substation is calculated iteratively according to theoretical models described in for example [10]. The heat load is constant for each case as well as the supply temperature set-point on the secondary side of the heat exchanger. The incoming DH-water temperature at the substation has no set-point in this case but is determined by the space heating circuit's DH-flow requirement in the substation and by the heat loss of the supply service pipe. However, the temperature drop in the supply pipe and, consequently the flow, will increase in case of damaged insulation.

Results, summer case

Figure 3 shows the temperature course obtained for T_s = 90 and 65°C at T_{DHW} = 50°C. The top two curves with round markers show the progress of the supply pipe. The temperature there is highest at the inlet of the pipe (to the left) and gradually decreases in the direction of the flow, down to 50°C at the outlet (to the right). The lowest curves, with triangle markers, refer to the return pipe and here, as the flow has changed direction, the temperature drops from right to left. It can be seen that although the curves show two different calculation cases as mentioned above, temperature variations are so insignificant that they are impossible to notice (the curves overlap). The calculation cases can be distinguished slightly when looking at the obtained heat holding flows, presented as stretches next to the right y-axis. The values form two groups, one for T_s = 90°C and one for T_s = 65°C, but the spread within the respective group is very small (about 3.5% increase between the case without moisture in insulation and the case where the moisture-damaged part of the pipe is longest). The flow that correspond to the summer case varies around 4.6-4.7 l/h.

Figure 4 shows the corresponding values for the heat losses of the service pipes. Here it is clear that the heat loss increases when the insulation is moist, about 7%, and one can distinguish the different cases. As mentioned, the circulation flow does not vary as much, which is because the increased heat loss comprises only a delimited distance of the total length of the service pipe.

Figures 5 and 6 show almost identical cases as the figures above, however, here the district heating water temperature at the DH substation is higher, T_{DHW} = 55°C. This corresponds to a substation where the control valve has a different setting or is of a different brand. It is seen that the temperature levels are slightly higher, which means that both the heat losses and the heat holding flows are also higher. Here the flow for the summer fall varies around 7.3-7.5 l/h.

Flow variations above are too small to be noticed at all when the flow is recorded in l/h. Figures 7 and 8 show two separate cases where we assume that there is a powerful leakage at the beginning of the service pipe, so that on the first 0.5 m pipe section, the volume between the media pipe and the protective jacket is filled with water in 80% and 100% respectively. For the following pipe sections, water saturation decreases proportionally for each section in such a way that it becomes 0% in the middle of the pipe (10 m). This is a serious deterioration of the insulation of the pipe. The temperature diagram in Figure 7 shows clear decrease in temperature in both cases compared to pipes with undamaged insulation. The heat retaining flow also increases significantly, about 25% in the first case and about 100% in the second case. Note, however, that in order to obtain a 25% increase in the heat holding flow, as much as 80% water content is required in the insulation in the first section of the pipe.

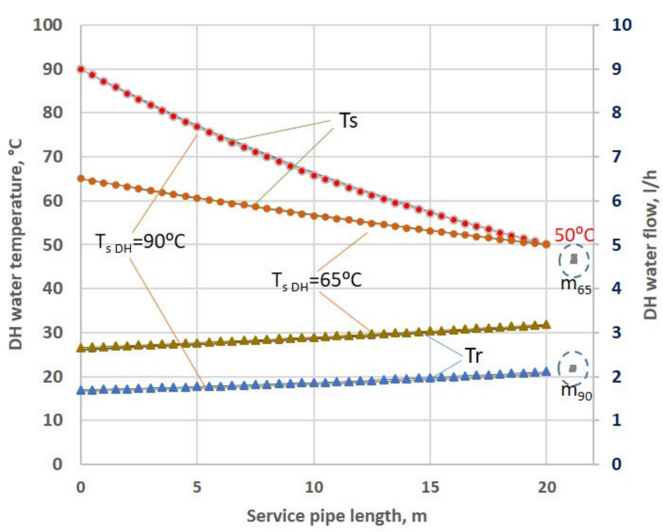


Figure 3. Temperature course in the service pipes when the hot water valve's set point is T_{DHW}=50°C. $T_{s,DH}$=90 and 65°C. The ideal case as well as cases where 0.5, 1, 5 and 10 m respectively of insulation are 7% filled with water are shown, but the difference between them is hard to see, except the flow (markers next to the secondary y-axis to the right).

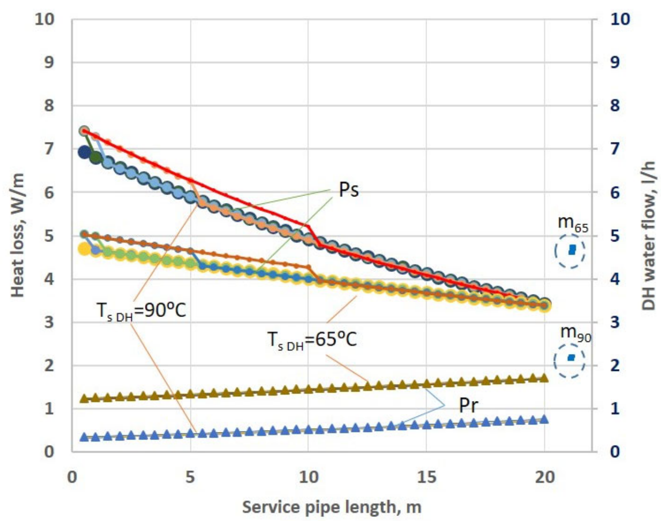


Figure 4. Heat losses from service lines in the cases shown in figure 1. Observe the slight variation of the holding flow (see the markers next to the secondary y-axis to the right). (T_{DHW}=50 °C. $T_{s,DH}$=90 and 65°C)

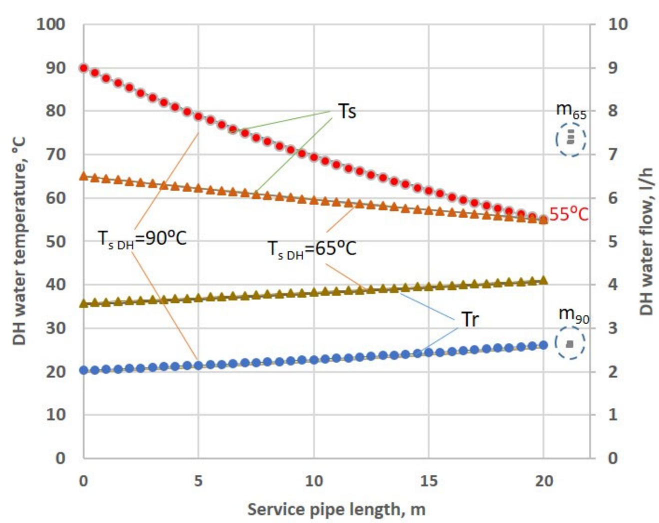


Figure 5. Temperature course in the service pipes when the hot water valve's set point is T_{DHW}=55°C. $T_{s,DH}$=90 and 65°C. The ideal case as well as cases where 0.5, 1, 5 and 10 m respectively of insulation are 7% filled with water are shown.

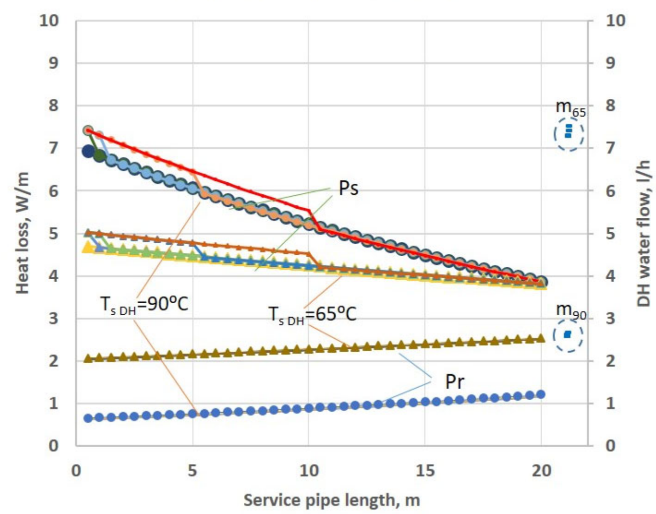


Figure 6. Heat losses from service lines in the cases shown in figure 5. Observe also variation of the holding flow (see the markers next to the secondary y-axis to the right). (T_{DHW}=55°C. $T_{s,DH}$=90 and 65°C)

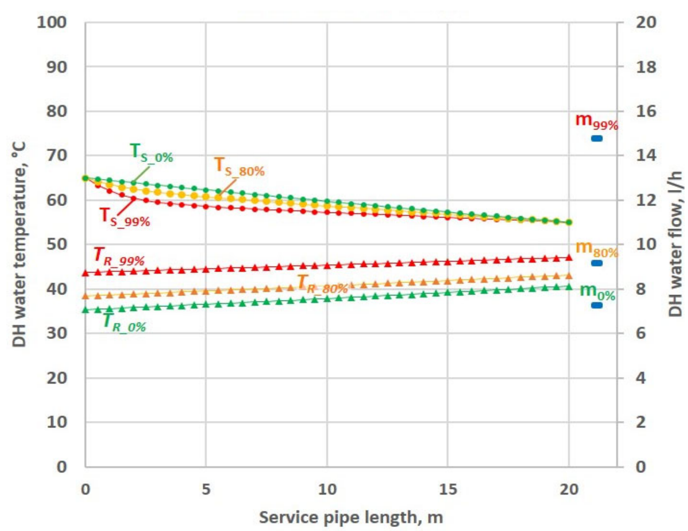


Figure 7. Temperature course in the service lines in case of a very serious leakage. The ideal case is compared with 80% and 99% water-filled sections at the beginning of the supply pipe. Temperature drops in the supply pipe can be seen. T_{DHW}=55°C. $T_{s,DH}$=65°C

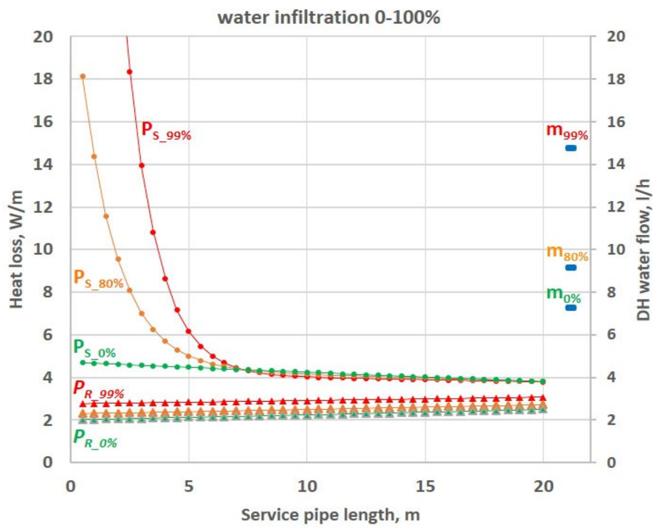


Figure 8. Heat losses from service pipes in the cases shown in figure 7. Note significant flow variation which, however, decreases sharply as soon as water damage decreases in extent. T_{DHW}=55°C. $T_{s,DH}$=65°C

Results from the summer case with Ts = 65°C are summarized in Table 1 were also the impact of the water content can be seen and compared to the reference case without any damages. The results show that, even though the heat losses from a damaged DH pipe increases compared to the reference case, the corresponding impact on the flow-rate through the heat exchanger is low. This is unless the insulation damage is very serious.

Table 1. Results from the summer case with Ts = 65°C. Δm indicates impact on flow-rate through the heat exchanger in case of damaged service pipe. ΔTps is constant here, 10°C.

Water content	m	$T_{ps,0}$	T'_{ps}	T_{pr}	T'_{pr}	$Q_{loss, supply}$	$Q_{loss, return}$	Δm
%	l/h	°C	°C	°C	°C	W	W	l/h
0	**7.28**	**65.00**	**55.00**	**40.67**	**35.35**	**84.8**	**45.1**	-
7%	7.54	65.00	55.00	41.06	35.82	87.7	45.9	0.3
80%	9.20	65.00	55.00	43.15	38.46	107.0	50.2	1.9
99%	14.79	65.00	55.00	47.13	43.73	172.1	58.5	7.5

Results, winter case

Results from the winter case with T_{ps} = 95°C at the branch and heat load corresponding to 100%, 75% and 25% of dimensioned heat load is presented in Table 2. In the winter case the value of T'_{ps}, the primary supply temperature at the heat exchanger, is dependent both on the flow rate and the heat losses from the supply service pipe which is shown in the table. As seen, the impact on temperature drop is at most 1.6°C for all heat loads even though the water content at point of leakage is 99% (which would imply a seriously damaged pipe).

Table 2. Results from calculations for a heat load T_{ps} = 95°C at the branch and T'_{ps} when entering the heat exchanger. ΔT_{ps} indicates impact on the temperature drop in the supply service pipe due to damaged service pipe. Δm indicates impact on the mass-flow through the heat exchanger in case of damaged service pipe.

Heat load	Water content	m	$T_{ps,0}$	T'_{ps}	Heating system		T_{pr}	T'_{pr}	$Q_{loss, supply}$	$Q_{loss, return}$	ΔT_{ps}	Δm
kW	%	l/h	°C	°C	T_s (°C)	T_r (°C)	°C	°C	W	W	°C	l/h
9	0	160.9	90.0	89.3	60.0	40.0	41.2	40.9	137.3	49.8		
9	7%	160.9	90.0	89.3	60.0	40.0	41.2	40.9	138.0	49.8	<0.01	<0.01
9	99%	163.1	90.0	88.5	60.0	40.0	41.1	40.9	281.0	49.6	0.75	2.16
6.75	0	115.6	90.0	89.0	51.6	36.6	38.9	38.5	136.9	45.5		
6.75	7%	115.6	90.0	89.0	51.6	36.6	38.9	38.5	137.6	45.5	0.01	<0.01
6.75	99%	118.1	90.0	87.9	51.6	36.6	38.8	38.5	281.1	45.5	1.03	2.52
4.5	0	73.1	90.0	88.4	42.8	32.8	35.5	35.0	136.6	39.5		
4.5	7%	73.1	90.0	88.4	42.8	32.8	35.5	35.0	137.3	39.5	0.01	<0.01
4.5	99%	75.2	90.0	86.8	42.8	32.8	35.4	35.0	279.6	39.4	1.59	2.16

Discussion and Conclusion

Using already available measurement values collected for metering and billing the customer for their energy consumption could potentially be of great benefit to the district heating companies when it comes to leak detection. Our research has however shown that it is hard to find valid input data for the calculations needed in the analysis. It is difficult to find information on how serious and how common water leakages and damage of insulation is for smaller service pipes. The same applies if you want to quantify impaired insulation capacity due to penetration of moisture into PUR foam used in pre-insulated district heating pipes. Therefore, the modelling of heat losses during leakage gives uncertain results and it is also difficult to determine how much the district heating companies could save on developing their leak detection tools by using analysis of meter values.

Our theoretical study and calculations show that, under the assumed conditions, it is impossible to detect small leaks with little intrusion of moisture into the insulation of the service pipe. The reason for this is because when the PUR foam is not mechanically damaged, it absorbs no more than 6-7% water. This roughly compares to the same magnitude of decrement of the insulation thickness, which is seen as a moderate change. Although we now assume that the holding flow in the service pipe is stationary for sufficiently time intervals to exclude impact of thermal inertia of the pipe, the resolution of the measured values is not sufficient to detect a 5-10% increase in heat losses from the service pipe at a flow magnitude of 5-10 l/h.

The situation changes in the case of serious leaks, where the foam cell structure is at least partially destroyed. In that case, it will suffice with a few meters of damaged insulation for the flow increase to be significant. However, there is a practical difficulty which is the stability of the holding flow. According to preliminary analysis of measurement data from single-family homes, occasions with stable conditions when the only heat load is the flow generated by the tap water circuit's self-acting control valve is hard to find. This is partly due to DHW tappings at night are quite common, and partly because the regulating valves of the DHW circuit usually have such a large capacity that their control range may be not sufficient to handle such small flows in a stable manner. The latter problem results in on-off control and, consequently, fluctuating flow. One could try to avoid the problem by averaging the flow throughout the whole night, but then the flow increases excluded by any DHW tappings would be impossible to sort out.

In Figure 9 data from night time meter readings from 6 different district heating substations' in the same neighbourhood are presented. The time resolution of the meter reading is 1 hour. As seen in the figure, the flow is not stable. In some cases, the flow varies within a large range, and that there are tappings (cases with high flow, high flow temperature, high cooling). Where there are no tappings, the flow varies due to unstable temperature control.

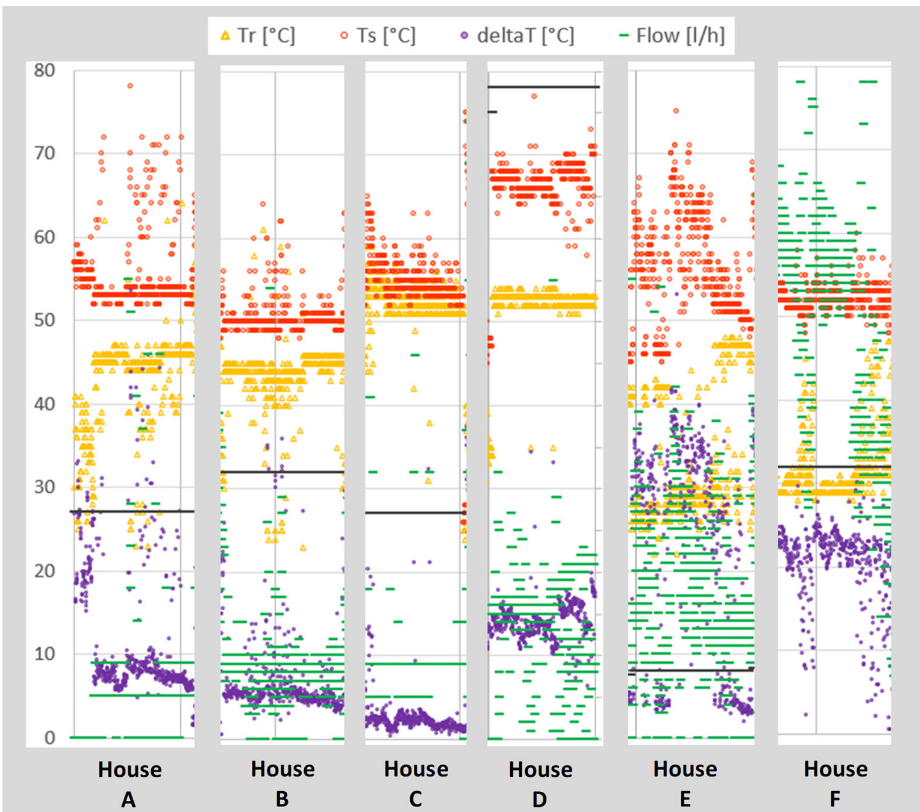


Figure 9. Supply and return temperatures as well as district heating water flow and estimated cooling of the district heating water during night hours in summer 2018 (July). The diagram is based on data from the utility Landskrona Energi AB.

The results of calculations concerning the cases representing the heating season show that the impact on the supply temperature at the DH substation is moderate. Since the calculations assume both stable heat load (including stable secondary temperature levels) as well as known, stable supply temperature at the DH network branch, the increased temperature drop in the service pipe would in practice be hard to note since these conditions rarely are fulfilled.

We believe that, with increased accuracy of the measured values from the energy meter, it would be possible to detect leakages in service pipes during summer period under condition that heat meter values could be measured with higher frequency than usual. That is if the obtained data set would allow for designing aids for leak detection in small house DH substations, for example by analysing transient temperature courses, a method corresponding the one described by Lidén et al. [13]. However, this method would only be valid for analysing damages in the supply service pipe, leaving the status of the return pipe still unknown since this method is limited to analysis of the supply pipe since the temperature conditions for the return pipe is unknown at the branch.

The method would be suitable during summer period and only during specific circumstances. Our conclusion is therefore that more extensive analysis is needed of possibilities to achieve measurement data of higher accuracy and at higher time resolution when employing the district heating companies' billing system.

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