Fault handling in district heating customer installations: experiences from Swedish utilities

Sara Månsson[a,b,*], Per-Olof Johansson Kallioniemi[a], Marcus Thern[a], Tijs Van Oevelen[b,c], Kerstin Sernhed[a]

[a] *Lund University, Faculty of Engineering, Energy Sciences Box 118, SE-221 00 Lund, Sweden*
[b] *VITO, Boeretang 200, BE-2400 MOL, Belgium*
[c] *EnergyVille, Thor Park 8310, BE-3600 Genk, Belgium*

Abstract

The district heating (DH) customer installations in current DH systems contain a variety of different faults that cause the return temperatures of the systems to increase. This is a major problem, since the focus in the DH industry is to decrease the system temperatures to utilize more low-temperature heat. Therefore, this study has focused on how the utilities that have low return temperatures work to keep their temperatures down, how they involve their customers in this work, and what faults are most common today. This was done by conducting a combined interview and survey study. The results showed that the two most important elements was to have physical access to and mandate of the customer installations, and to maintain a good and close customer relationship. The results also showed that many faults occur in the customers internal heating systems, or due to leakages somewhere in the installation. Overall, the results show that it is indeed possible to work close to and affect the customers to obtain lower return temperatures from the customer installations, and that the most common faults are rather easy to eliminate as long as the utilities gain physical access to the entire customer installations.

Keywords: District heating substations, Experience from industry, Fault diagnosis, Faults in substations, Poor substation performance

1. Introduction

Today, more than half of EU's energy is used for heating and cooling, and in 2016, approximately 75 % of the energy used for heating and cooling purposes was based on fossil fuels [1]. Hence, the heat supply sector needs to find solutions that reduce the fossil fuel dependence and utilize renewable heat sources instead. District heating (DH) has been identified as an important part of the future smart energy systems due to the ability of providing local, affordable and low-carbon heating [2]. DH will play an important role in increasing the energy efficiency of the energy systems due to the ability to make use of available heat sources that would otherwise go to waste, including large-scale heat pumps, large thermal storage, Combined Heat and Power (CHP) plants, solar thermal energy, geothermal energy and industrial waste heat [3, 4, 5].

In order to reach the full potential of district heating as described above, it is critical that the current technology develops further. This development has been described in a paper written by Lund et al., where the 4th generation of district heating (4GDH) has been defined [6]. In the paper, the authors have described that the future DH systems must be able to use recycled low-temperature heat and renewable energy to supply low-temperature district heating for space heating and domestic hot water preparation with low heat losses. This includes decreasing the temperature levels of the DH systems to levels around 50/20 °C supply and return temperature [6]. Today, the average temperature levels of most systems are much higher than this. For example, the Swedish DH systems have annual average temperature levels of 86.0 °C sup-

*Corresponding author
Email address: sara.mansson@energy.lth.se (Sara Månsson)

ply and 47.2 °C return [7].

The temperature levels of the DH systems depend on the climate where they are located, what heat sources are available in the vicinity, the age of the DH system, the age of the buildings in the system and the building standards applied when the building was constructed, as well as the temperature demands of the heat consumers in the systems [8, 9]. The supply temperature is determined by the heat supplier and varies with the outdoor temperature. The return temperature is determined by the aggregated result from all cooling processes in the individual customer installations (i.e., the internal heating system of the building and the DH substation) [8]. Hence, the return temperature will increase if the cooling processes in the installations are not working as they should.

The design of the customer installations varies, depending on what country and system the installation is located in. In some countries it is common practice to not have any hydraulic separation at all, so called direct connection, but the most common design is to have an indirect connection where a heat exchanger separates the water in the internal heating system from the water in the DH system [8].

The substation consists of a number of different components, and the design and connection principle of the substation also varies. The two most common connection principles are the parallel-connected and the 2-stage connected substation [10]. Figure 1 displays the general outline of a parallel-connected substation with hot water circulation in the internal heating system. The figure includes the most common components of the customer installation.

According to previous studies there are two common reasons to why the return temperatures from the customer's installation are higher than they theoretically could be: faults in the customer's internal heating system and faults in the customer's substation [8, 11, 12]. In fact, the existing DH substation technology enables temperature levels lower than this, but due to the poor cooling performance of the customer installations these temperature levels are seldom reached. This is a strong indication that the faults in the customer installations have to be detected and identified in order to decrease the current return temperature levels of the DH systems.

It will also be of great importance to be able to detect these faults at an early stage in the future 4GDH systems. If the faults are not detected rapidly the faults will prevail in the systems, making it impossible for the utilities to maintain the low temperature levels of 4GDH. Automatic fault detection methods could play an important role to mitigate these problems. Automated heat meter readings provide a lot of relevant data containing the signatures of faulty substations. This enables computer-automated analysis to evaluate the performance of individual substations and detect faults. To know what faults such a fault detection tool should be able to detect, it is important to know what the most frequently occurring faults are today and in what way they impact the return temperature levels.

Two key issues to eliminating the faults is the utility's ability to communicate the information about the faults in the installations to the customers, and how to encourage the customers to correct the faults in their installations. Therefore, the purpose of this study was to investigate how utilities are currently working with their customers to decrease the return temperatures from the customer installations. In order to find good strategies for working with improving the cooling in the DH systems,interviews were carried out to identify the key successful measures that utilities are currently taking to reach lower return temperatures and how their customers are involved in the process. The aim was also to identify the most frequently occurring faults in the DH installations today, and how the utilities are working to eliminate this.

The study consists of a literature review, a survey which was sent to Swedish district heating utilities, and a qualitative interview study with representatives from Swedish DH utilities. The focus of the literature studies and the survey was to investigate what faults occur in the system, how often they occur, and to explore what strategies and methods the utilities use to eliminate the faults. The focus of the interview study was to investigate how the utilities are working with their customers and the customer installations today; what incentives they have to work towards decreased return temperatures, what incentives they provide their customers with so that they are interested in correcting faults in their installations, and how the utilities are working to eliminate faults in their customers' installations.

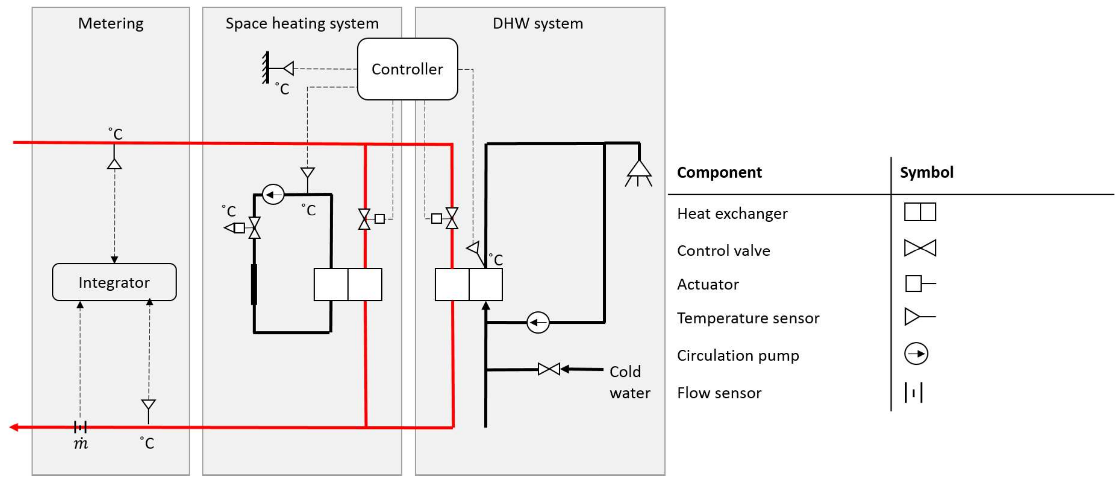

Figure 1: General outline of parallel-connected substation with hot water circulation

2. Methodology

2.1. Survey study

To investigate the faults that occur in the current DH system, a survey study was conducted. The first part of the study was to establish what faults to include in the survey. This was done by conducting a literature study, as well as an interview with a leading district heating expert. The literature review gave a comprehensive picture of the historical fault distribution, and what faults should be investigated further in the study. Information of the different faults was primarily collected among scientific articles and research reports conducted by various research institutes. The main purpose of the interview was to create a fundamental understanding of the faults, as well as identifying the faults that were most likely to occur in the modern district heating systems.

Based on the results from the literature review and expert interview, five different categories of faults were identified. The categories were based on what component or part of the customer installation that the fault occured in. The five different categories are: (i) heat exchangers, (ii) control system and controller, (iii) actuators, (iv) control valves, and (v) internal heating system of the customer.

These results were then used to create a survey which was sent to DH utilities in Sweden. In the survey, the utilities were asked to give information about how common certain faults were, how they went about to identify the different faults, and what the fault distribution looked like. The survey also included questions regarding information about the utilities themselves, their price models and service agreements, as well as how they utilized customer data. The price models and service agreements were of interest since they may be used as an incentive for the customers to work with faults in their installations more actively. The survey also provided plenty of space for the utilities to add additional faults that were not included in the survey to begin with, and the possibility to write down comments and explanations about the different faults. The survey was sent to 139 utilities that were all members of the Swedish non-profit industry and special interest organisation Swedenergy - Energiföretagen Sverige. 56 of the utilities answered the survey.

2.2. Interview study

The interviews were conducted during the fall of 2018, and representatives from six DH utilities were interviewed during the study.The participating utilities were all located in Sweden. The utilities were of varying sizes and delivered varying amounts of heat to their customers. The interviewees were people involved with, or responsible for, the operation and maintenance of DH production, distribution or end user.

The interview study was conducted using a qualitative, semi structured approach in order to obtain in depth knowledge of how the DH utilities were working with their customers in the context of decreasing the return temperature levels. Before the interview, a number of questions were prepared but the semi structured approach allowed for the interviewer to follow up the responses of the interviewee during the interview and ask new questions if needed. Before the interviews were conducted, a number of themes and questions were prepared in order to facilitate the interview process.

Four out of the six interviews were conducted face-to-face by the same interviewer. They were recorded and took approximately one hour to complete. The two remaining interviews were conducted as phone interviews by the same interviewer and recorded via the phone. The interviews were transcribed word for word, and the material obtained was then analyzed by dividing the answers thematically into four different categories: (i) incentives for the district heating companies, (ii) incentives for the district heating customers, (iii) access to and mandate of the maintenance of the district heating substations, and (iv) analysis methods for finding porrly performing customer installations.

3. Faults in customer installations

The literature review and the expert interview showed that a number of different faults may appear in the customer installations. However, several faults do not affect the comfort of the customer. This means that a fault might be present in the substation without the customer experiencing any issues with the space heating or the DHW preparation [13].

In this study, five different categories of faults have been identified. The categories are based on what component or part of the customer installation the fault occurs in. The five different categories are: (i) heat exchangers, (ii) control system and controller, (iii) actuators, (iv) control valves, and (v) internal heating system of the customer. Below follows a review of the most common faults that occur for the different components or faults.

3.1. Heat exchangers

The category includes faults that are related to the heat exchangers of the substation. Depending on the design of the substation, there might be one, two, or more heat exchangers installed. All of these need to perform well for the substation as a components to perform well.

The literature shows that faults related to the heat exchangers themselves most commonly include fouling of heat exchangers [8, 13, 14, 15]. This can be described as unwanted deposits on heat transferring surfaces which cause a resistance to heat transfer and flow in the heat exchanger [16]. However, a study conducted by Wollerstrand and Frederiksen show that moderate fouling of the heat exchanger might lead to higher heat transfer at low flows [17].

Another fault related to the heat transferring capability of the heat exchangers is that some heat exchangers by mistake are installed so that the DH water and the water in the customer's internal heating system are flowing co-current instead of counter current [14, 15]. Other faults include leakages from the heat exchanger itself and uneven flows in heat exchangers connected in parallel [15, 18].

3.2. Control system and controller

The category of the control system and the controller includes the controller itself, the temperature sensors, the connections between the sensors and the controller, and the connections between the actuators and the controller. Hence, there is a number of components that may be faulty and so there is a number of different faults that may occur in the control system.

The controller itself may break down causing a completely uncontrolled system [14]. It might also be that the controller is installed incorrectly in the system. This occurs if the wrong input signal is connected to the wrong port on the controller. Since the controller is receiving an incorrect signal the control sequence of the installation will be disturbed [15].

With regards to temperature sensors, a number of different faults may occur. The temperature sensors may be broken, not sending any signal at all or a completely incorrect signal to the controller [14]. The temperature sensors might also be placed on the wrong pipe, leading to a disturbed control sequence since the sensor is measuring the incorrect temperature [8, 18]. They may also be assembled incorrectly, so that they are mounted loosely to the pipe where they are measuring the temperature [14, 15]. The measurements from the temperature sensors may also be distorted by noise or drift (bias change) [19].

When having no hot water circulation, the water in the DHW system will be stationary and will cool down over time. The temperature sensor in the DHW system will sense this and send a signal to the controller to increase the temperature again. Since there will be a time delay before the newly heated water reaches the sensor, the control signal to increase the water will continue for longer than necessary. This causes the DHW supply temperature to overshoot [20]. Therefore, the temperature sensor measuring the supply temperature in the DHW system should be placed as close to the heat exchanger as possible [10].

3.3. Actuators

The actuators control the position of the control valves in the customer installation. The actuators are connected to the valve via a valve stem. Due to wear and tear, the connection between the stem and the valve may become poor, or the actuator may break down. If this happens, the control valve will be stuck in the position it was when the actuator broke down. This might lead to too large or too small flow in the installation, causing no response to the heat demand in the building [21].

The actuators have a number of different parameters that need to be taken into consideration when dimensioning the actuator for the installation. Among else, it is important that the actuator is dimensioned for the correct pressure so that it has enough driving force to change the position of the valve [10].

The actuators also have different running times, which means that they open and close the valves with different rates. In the DHW system, the actuators should have a short running time since the valves need to be able to open and close rapidly when a demand for tap water occurs. On the other hand, in the space heating system the actuators need to have a long running time since the temperature in the space heating system should change slowly to obtain the desired room temperature. These actuators may be interchanged by mistake at installation, which cause poor control of the both systems [14].

3.4. Control valves

The faults related to the control valves in the customer installation may arise if the valve is overdimensioned. This fault is especially common for the DHW system in older buildings, due to a historical practice to overdimension the valves. This causes an undesirably large change in the flow when the valve position changes, and that the valve cannot control small flows [13, 18]. The valve may also be too small for the flow that is needed in the installation, which means that it will not be able to obtain larger flows than the valve is able to transmit [18].

Since the space heating system is not used during warmer months, the valve on the space heating system will be in the same position during this time. This may cause the valve to get stuck in a closed position [22]. It may also happen that the valves seize in an open position or that they are completely stuck [14].

Valves are also susceptible to wear and tear. Over time, the disc of the valve may erode due to cavitation if there is a large differential pressure over the valve [23], causing the valve to leak in a closed position [14].

3.5. Internal heating system of the customer

The category of faults related to the internal heating system of the customer include a large variety of faults, since the design of the internal heating system varies between the installations. In some DHW installations an additional heat exchanger, a pre-heater, is installed in series with the heat exchanger seen in Figure 1. This solution is used to pre-heat the incoming cold water to maximize the heat exchange in the installation [8]. If this is the case, the circulation pump should be installed between the pre-heater and the final heat exchanger. If it is installed before the pre-heater, the return temperature of the installation increases [14].

If the DHW circulation is missing or broken, the water in the DHW system will be standing still in the pipes. As described in section 3.2 this may cause a poor control of the DHW temperature, especially if the DHW temperature is placed at a distance from the heat exchanger. It is also important that the flow in the DHW circulation is not too large, since the cooling in the heat exchanger will decrease.

The temperature demands in the customer installation is determined by the temperature levels for which the space heating system is dimensioned, and by the set point value that the DHW system requires to prepare hot water [10]. This means that if the temperature demands are high, maybe even higher than the temperature of the DH water, the flow on the DH side of the heat exchanger will always be large causing poor cooling and high return temperatures as a result [8].

When a building is connected to the DH system, the internal space heating system needs to be hydraulically balanced to make sure that the system is able to deliver the correct amount of heat to all heat delivery points in the system. This is done by adjusting the balancing valves in the system so

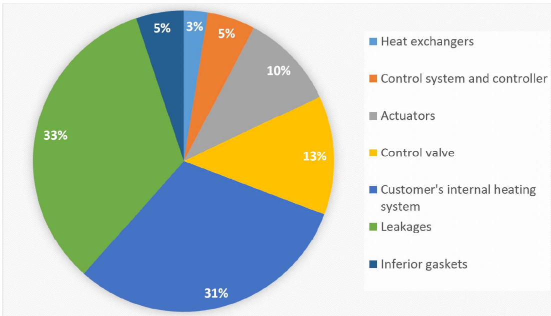

Figure 2: Distribution of the single most common fault in the utilities, sorted by category

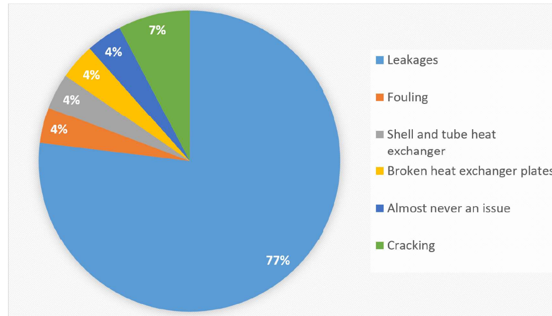

Figure 3: Distribution of the most frequently occurring faults related to the heat exchangers

that the opening position of the valves closest to the heat exchangers is smaller than the valves located further away in the building. This cause the flow to travel with the same flow rate as ti the ones closer to the substations, delivering heat to the more remote radiators. If this is not done correctly, the return temperature from the installation will increase [24].

The radiators in the space heating system are most commonly controlled by thermostatic radiator valves. If these are not working correctly, or are missing, the flow in the radiator system will be uncontrolled [15].

4. Results and analysis - Survey

The results from the survey study are based on the answers from the 56 utilities who answered the survey and that stated that they worked actively with faults in the customer installations. Three of the surveyed utilities answered that they do not work with the maintenance of the installations in their systems.

Figure 2 show the distribution of the faults that were reported to be the one most common fault in the utilities, sorted by category. As can be seen in the figure, there were two additional fault categories that emerged in the answers, that was not included in the survey from the beginning: leakages and inferior gaskets. Leakages include leaks in all parts of the customer installation and substation, and inferior gaskets include all gaskets that are used in the substation. The figure shows that the largest fault category according to the survey was leakages (33 %), closely followed by faults in the customers' internal heating systems (32 %).

As can be seen in Figure 2, the smallest overall fault category was the heat exchanger category. Figure 3 displays the fault distribution for this category. As can be seen in the figure, it is clear that leakages were experience to be the most common reason to faults in heat exchangers. The leakages include leaks that occur due to incorrect installation of the heat exchanger, and leaks in the pipings connected to the heat exchangers. This indicates that the utilities may have answered "leakages" instead of "heat exchanger faults" when asked what category constitutes the largest fault category in their utility. A reason to this might be due to the way the question in the survey was formulated. When reading the word "heat exchanger", many people think of the entire DH substation, and not only the heat exchanger itself. It might be that the respondents have made this connection instead of thinking of the heat exchanger as one single component. The second most common faults was cracking of the heat exchanger plates (7 %), which the utilities have experienced when water hammers occurs in the system.

Faults in the control system and controller corresponded to approximately 5 % of the overall fault distribution. Although this was one of the categories that occur less frequently when regarding the overall distribution of faults, it was clear in the responses that the number of faults that may occur in this category is large and that many utilities do experience frequent occasions of faults in the control system and controller. Figure 4 displays the fault distribution of the faults related to the control system and the controller. As can be seen in the figure, 49 % of the utilities answered that the most common control system fault was that the controller was broken. The second most common fault was broken temperature sensors (16 %), and the third most common fault was temperature sensor giving

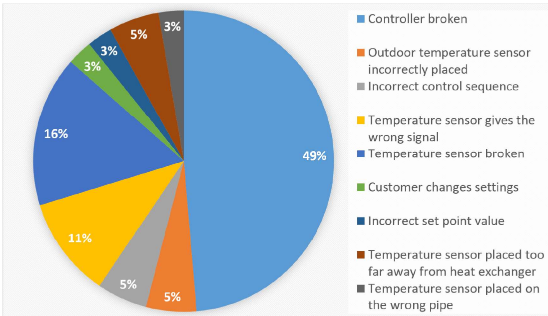

Figure 4: Distribution of the most frequently occurring faults related to the control system and controller

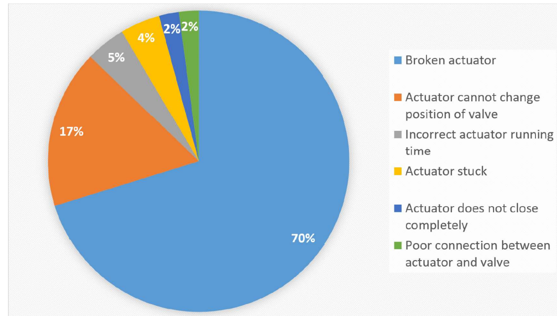

Figure 5: Distribution of the most frequently occurring faults related to the actuators

the wrong signal (11 %). This indicates that a large share of the faults in the control system and controller was an effect of broken or poorly performing components. The utilities also experienced that incorrectly placed temperature sensors was a frequently occurring problem, corresponding to a total of 15 % of the faults (incorrectly placed outdoor temperature sensor, temperature sensors placed on the wrong pipe, and temperature sensors placed too far away from the pipe). All of these faults lead to poor control of the internal heating system of the customer, and they should all be recognized by the customer since they affect the customer comfort; either in terms of an unwanted change of the indoor climate if the temperature sensor is placed incorrectly, or in terms of unwanted DHW temperature levels. However, the utilities agreed that it was beneficial to be able to detect these faults at an early stage since they all lead to higher than necessary return temperatures. One interesting fault that emerged in the survey was that the customer itself may occur as a fault in the system. This problem occurred if the customer changed the set point values or control curve of the controller manually. The utilities experienced that this happened when the customers felt that their indoor temperature was too low, and changed the settings in order to try and increase the temperatures. In most cases, this did not give any effect since the low indoor temperature was due to faults located elsewhere in the installation and not due to how the system was controlled. The only effect of the change in the controller settings was that the flow through the substations increased, with increased return temperature levels as a consequence.

The fault distribution of the faults related to the actuators can be seen in figure 5. This category corresponded to approximately 10 % of the overall distribution of the fault categories. As can be seen in the figure, 70 % of the actuator faults were a result of broken actuators. Some of the utilities experienced that this fault may occur in the DHW system if the control valve it was connected to was too large. If so, the actuator had to operate constantly to attempt to control the flow, which caused the actuator to break down prematurely. The second most common fault for actuators was actuators that could not change the position of the valve, due to oversized valves or that the actuators were not dimensioned for the current pressure (17 %). The utilities experienced that this was a fault that the customer may not notice if it was located in the space heating system where the radiator thermostats control the final heat supply. Therefore, the utilities wanted to detect this type of fault at an early stage.

Figure 6 displays the fault distribution for the faults related to the control valves. In this category, overdimensioned control valves were the most common fault (35 %). However, some of the utilities never had experienced that this was a problem while some of the utilities experienced that this was their most common fault. The two second most common faults were control valves leaking in an open position (27 %) and control valves seizing in a closed position (27 %). The leaking control valves were most commonly due to wear and tear of the control valve itself, or in the connection between the control valve stem and the actuator. When this happened the valve could not close completely, causing a small seeping in the closed position. The seizing control valves most frequently occurred in the space heating system at the beginning of the heating season, when the control valve was stuck

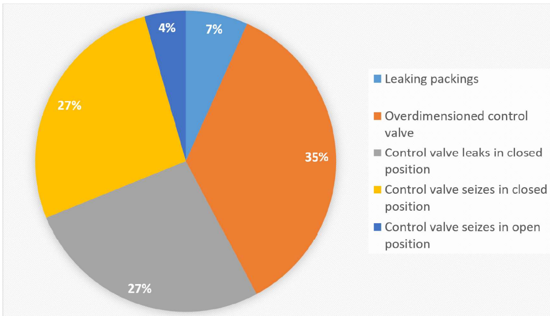

Figure 6: Distribution of the most frequently occurring faults related to the control valves

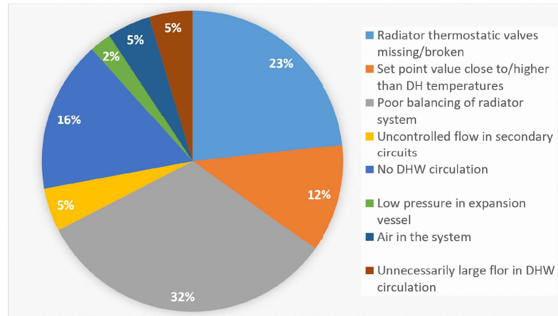

Figure 7: Distribution of the most frequently occurring faults related to the customer's internal heating system

in a closed position after the summer months when the space heating system was not used.

Figure 7 displays the fault distribution for the faults related to the customers' internal heating systems. The utilities experienced that the most common issue was poor balancing of the radiator system (32 %). Most utilities stated that the balancing of the radiator system was the customers' responsibility, but that they would be happy to advise the customers about the balancing. However, most of the utilities experienced that the main reason to poor balancing was that the customers were lacking knowledge of how to perform the system balancing and that they in some cases did not ask for professional help. The second most common fault was missing or broken radiator thermostatic valves (23 %). The utilities responded that many of the faulty thermostatic valves were located in older buildings where the valves had broken down due to wear and tear, causing poor space heating. Systems without DHW circulation was also mentioned as a frequently occurring issue (16 %), primarily in smaller houses. The consequences of this issue were increased return temperatures and poor DHW preparation. Another fault that was frequently occurring is that the set point values in the customers' systems were close to, or higher than, the DH supply temperatures (12 %). Some of the utilities mentioned that this issue may occur during the summer months due to low DH supply temperatures in the outer parts of the DH system, where it was harder to maintain higher supply temperatures. The utilities also stated that high customer radiator supply temperature set point values were an issue which led to a high overconsumption of flow in the installation, which indicates that it is necessary to find these installations as soon as possible.

50 of the 56 participating utilities utilized analysis of customer data in some way to detect deviating installation behaviour. There were a number of different ways to do this, and Figure 8 displays what the different utilities primarily measured to perform their analysis. The utilities had structured their analysis work in different ways. Some of the utilities performed analysis a few times per year, while other received instant alarms from their measurement system if a large deviation from the normal installation behaviour occurred. Others performed monthly controls of their customers' data to investigate whether the behaviour if the installation deviated significantly from its normal behaviour.

As can be seen in Figure 8, 19 of the utilities primarily performed analysis of the return temperature levels from their customers' installations to identify the poorly performing installations. The main method was to check the temperature levels, identify the installations with the highest return temperatures, and contact the customers in question. Some of the utilities administered the customer contact themselves, while others used subcontractors in the plumbing industry to contact the customer and investigate the installation further. Whether the utility performed the work themselves, or used a subcontractor, depended on the size of the DH system and if the number of employees at the utility allowed for doing this kind of maintenance work.

17 of the utilities stated that they performed analysis on a combination of measurement values from the customers' meters. This data was primarily used for billing purposes, but the utilities also utilized it for analysis. Nine of the utilities performed analysis of the cooling of the substation, while seven used the overconsumption, method to

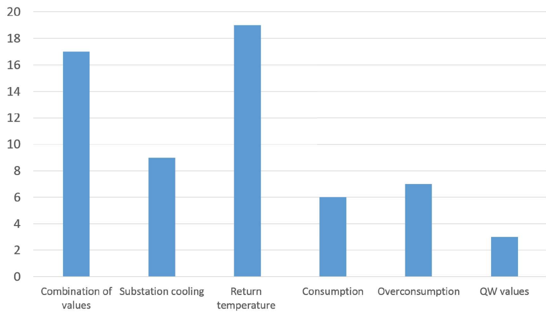

Figure 8: Distribution of different measurements used to identify poorly performing customer installations

identify installations that was not performing well. The advantage of the overconsumption method s that it gives a possibility to rank the installations according to how large their impacts on the system are, since an installation with a larger heat demand will have a larger overconsumption if the installation is poorly performing in some way [11].

The utilities that investigated their customers' consumption (six utilities) often controlled how much heat their customers consumed during one month, compared to an expected heat consumption. This gave the utilities an indication that something may be wrong, but further investigation of the installation was needed since a change in the heat demand may occur due to natural reasons, e.g., new residents or an unusually cold month. However, the utilities also stated that in some cases it was not a change in the customer behaviour that had occurred; rather an incorrect heat demand estimation done by the utility.

As can be seen in figure 8, three of the utilities utilized so called QW values to investigate the performance of their customers' installations. The QW values are calculated by dividing the flow rate with the heat used in the building during, e.g., one month. This provided the utilities a figure that could be used to perform comparative analysis of installation data from installations of different sizes and heat demands.

5. Results and analysis - Interview study

The district heating utilities who participated in the interview study were all found to work with their customers' return temperatures in different ways. Some of the utilities put a lot of emphasis and work into reducing the costumers' return temperatures, while others considered their low return temperatures as an added bonus when working actively with other issues in their systems.

In general, the utilities agreed that it was most urgent to identify customers who had high return temperatures combined with a large heat demand. These customers were identified to have the largest impact of the system performance and were the ones that were most urgent to improve the performance of.

5.1. Reported incentives for the district heating companies

The interviews showed that there were different incentives for DH utilities to work with their customers' return temperatures. One common incentive was that the systems had flue gas condensation in their production facilities, which benefit from the low return temperatures since the efficiency of the heat production increases when the return temperatures from the DH system decrease.

There were also some incentives related to how the heat was used in the DH systems. In cases when a utility served as both heat distributor and heat transmitter, i.e. when a large amount of heat was transferred through the DH system each year to another system, it was important to decrease the customers' return temperatures mainly to prevent the need of increased pumping in the system.

5.2. Incentives for the district heating customers

From the interviews, it was clear that there are many different incentives that could be used to get the customers to address problems and faults in their installations. Some of the utilities utilized their relationships with their customers to create incentives, while other created incentives in terms of additional costs if the installations were not working correctly.

The overall most important factor to increase the customers' willingness to contribute to and work towards lower return temperatures was identified to be the relationship between the DH utility and their customers. The experience was that the customers were willing to pay the costs of correcting faults and problems in their installations, as long as the information about why and how was sufficient and easy to understand. This information was distributed to the customers in different ways, depending on what other measures the utility took to create incentives for their customers to work with their return temperatures. In the smaller DH systems, it was common practice to visit all customer installations once per year to examine the installations and substations on site. This provided the utilities with an excellent opportunity to talk to the customers and improve their customer relationships.

One common monetary incentive was to have a flow component in the basic price models for one or several types of customers. This meant an additional cost for the customers if a large amount of water passed through the substation during one month. The flow component did not constitute a large share of the final invoice, but the experience was that it was enough for the customers to become interested in different ways of reducing the flow through their substations. However, the experience was that the flow component itself was not enough to create an incentive for the customers; it was also of great importance to inform the customers of the reasons behind the flow fee and what they could do to decrease the amount of flow passing through their substation. Without this information, the flow component was seen as an additional cost only that the customers did not understand and therefore did not want to pay for.

In some companies the flow fee was used as a last and final action, if no other actions from the utilities encouraged the customer to improve the installation performance. If using the flow component in this way, the customers should first be informed about the high return temperatures and what this means to the customer and DH system, and be helped to find a solution to the problem. However, if the customer would not be susceptible to the information and proposed solution, a flow component might be introduced. The customer would then have to pay for the flow until the problem or fault in the installation has been solved. The utilities experienced that the need for this type of measures mostly occurred if the installation was not used by the owner of the installation but rented out to someone else. If so, the additional cost did not affect the owner him or herself since an increase of the rent for the tenant would cover the additional heating costs for the owner.

In general, the interviews showed that the customers were willing to work with the utilities to decrease their return temperatures in most cases, even though no clear incentive for each individual existed. However, there was a difference between the smaller and the bigger utilities where the smaller utilities experienced that it was easier to convince all of their customers to work with their installations. The smaller utilities also experienced that their customers were willing to work with their installations due to the collective responsibility to keep the DH prices down. The larger utilities experienced that it was relatively easy to target their largest customers, but stated that it was harder to work with and convince their smaller customers to improve their installation performance. This was both due to the large amount of manhours would be needed to target all customer installations, as well as the fact that smaller installations have a smaller system impact when performing poorly. Hence, it is more cost efficient to target the larger customers first.

5.3. Access to and mandate of the maintenance of the district heating substations

One of the most important issues regarding the work with the customers' installations was to gain insight into how the installations performed, and get physical access to the customer substation. The general conclusion was that the utilities gained a lot by being allowed into the customers' properties to physically examine the substation. They also experienced that their customer relationships improved significantly since they not only gained physical access to the installation and substation - they also gained access to the customer. This meant that they were able to show and explain to the customer in person what happened in an installation if a fault occurred, and why it is beneficial to have an installation that performed as well as possible.

One common way of gaining access to the customers' installation was for the utilities to sign service agreements with the customers. This created a natural reason for technicians from the DH utilities to visit the customer's installation and make sure that the installation was performing well. The experience was that the outcome of the service visits was most beneficial when doing the visits at a regular basis, with at least one visit every other year. During the visits, the technicians investigated the performance of the installation by performing an inspection where the different parts of the substation were tested and made sure to work as they should. If something in the installation was broken, it was common practice to offer the customer some sort of solution. This could be that the utility replaced the broken component free of charge, or that they gave the customer an offer about the cost to replace the component. This gave the customer the possibility to decide if the utility should perform the work, or if someone from a plumbing company should get involved. The utilities stated that most customers chose to accept the offer from the DH utility rather than involving an external plumbing company.

Other ways of gaining access to the customers' installations at a regular basis was to offer the customers a free of charge survey of the installation when needed, and to allow the customers to call the utility at any time if something in their installations was not working correctly. This gave the customers a sense of security and trust towards the DH utility, which the utilities considered to be a big advantage in their customer relationships.

5.4. Analysis methods for finding poorly performing customer installations

During the interviews, it became clear that it was common practice to use different varieties of analysis methods to find the customers with undesirably high return temperatures. The methods varied in complexity, but common traits were that the methods were based on customer data from heat meters that were normally used for billing purpose. The different methods are summarized in the bullet list below and further explanation follows below.

- Monthly checks of customer billing data
- Quality index based on the installations performance
- Analysis of return temperature levels
- Analysis of flow
- Overconsumption method

The monthly checks of the customer billing data were used to identify whether a customer deviated significantly from its normal behaviour. In one utility, customer data was utilized to create a quality index which was based on the installation performance, as well as the location of the installation in the system. The quality index was then analyzed on a daily basis and if the index changed rapidly or the index pattern started to deviate from the normal behaviour, a service technician contacted the customer immediately to investigate the installation further.

The analysis methods were in most cases based on the temperature levels at the customer substation. The return temperatures or cooling performance of each individual customer installation were investigated, as well as the flow, to decide what customers to prioritize. The overconsumption method was also used by some utilities. The overconsumption can be described as the additional amount of DH water that has to pass through the substation in order to deliver enough heat when the installation contains a fault [8]. The overconsumption method takes into account the delta T of the substation, the flow through the substation, and the amount of heat being delivered to the customer. Hence, the customer with the largest overflow should be prioritized when using this method.

6. Discussion

The work conducted in this study clearly shows that high return temperatures and faults in the customer installations were viewed as important issues that needs to be addressed in order to enhance system efficiency in DH systems. It will also be of great importance to work with these issues in the 4GDH systems, to avoid unwanted increases of the system temperatures since lower system temperatures give less room for installations to deliver higher return temperatures than they are expected to. This means that faults in customer installations will have a larger system impact in the future systems. The interviews showed that the current DH utilities have a number of different work procedures for fault handling in customer installations that could be implemented in the future systems as well.

When investigating how the different utilities were working with fault handling today, it was clear that different utilities worked in different ways depending on size of the DH system, number of employees at the utility, and the amount of resources that could be allocated to this work. However, one of the most important aspects of the fault handling process was to create a close and good relationship with the customers. Although the utilities worked in different ways to obtain this, they all recommended to put an effort into providing their customers with clear incentives to why it is important to have a well performing installation and how to obtain this. In new and future DH systems, this could be done already from the start in order to create a good foundation to have well performing customer installations continuously during the operation of the DH system by signing service agreements with the customers and make sure to show the customers that the lower system temperatures are beneficial for the customers as well.

The utilities stressed the importance to gain physical access to the customers' installations. By achieving this, it was possible to gain insight into how the installations were performing and to further improve the customer relationship. If the utility also had a mandate to fix minor faults free of charge for the customer, such as replacing a broken temperature sensor, there were great possibilities to enhance the customer satisfaction while improving the overall system efficiency by eliminating faults in the installations.

The physical access to the customer installation was primarily achieved in two different ways: by signing service agreements with each individual customer, or to include a yearly inspection in the DH price. Some of the utilities included a small fee for the yearly inspections, while others made this free of charge. By including this in the price, the utilities had the possibility to visit all customers at least once a year. This gave them a large advantage in terms of access to and mandate of the customer installations, and gave large opportunities to identify and eliminate more faults in the customer installations. Therefore, it might be a good idea to include service agreements or inspections in the price model in the future DH systems.

From the answers from the interviews and the survey, it was clear that most utilities had different ways to find the poorly performing installations using customer data in different ways. The most common analysis method was to investigate the return temperature levels from the individual substations. This was due to the fact that most faults and problems in the installations caused higher flows and return temperatures.

Looking at the distribution of faults, the survey showed that leakages was experienced to be the most common category of faults, followed by faults in the customers' internal heating systems. These faults may be hard to detect during service visits, since the technicians may not be allowed by the customer to inspect all different parts of the installation. Therefore it would be beneficial to be able to detect these faults by investigating customer data. However, some of the faults may be hard to detect in the data that is available today, which in most cases is the data used for billing purposes. This indicates that it might be a good idea to implement more measurement points in the customer installations in the future systems. This is due to the fact that it might be very hard, maybe even impossible, to identify specific faults when only analyzing data from the DH system.

Regarding the results from the survey, it is important to keep in mind that the participating utilities were located in Sweden. This may have affected the results, since it is possible that some faults do not occur in the DH systems due to national conditions. One example of this is that fouling of heat exchangers seems to be a relatively unusual problem according to the utilities, while it is mentioned as one of the most common faults in the literature. One reason to that fouling is not as frequently occurring in the survey as expected may be that the overall water quality in the Swedish DH systems is high due to the measures that have been taken to improve the quality. Another reason may be that the study has been conducted in Sweden, where it is common practice to use compact plate heat exchangers which generally are less exposed to fouling.

The results from the survey may also have been affected by the response rate. 56 out of 139 utilities answered the survey, corresponding to a response rate of approximately 40 %. It might be that only utilities that experienced a frequent occurrence of faults answered the survey. However, when analyzing the survey responses it was clear that the participating utilities had different fault occurrence levels and that the responses also included utilities that did not experience a large amount of faults in their systems.

Regarding the results from the interview study, they should be seen as examples of how the Swedish DH utilities are currently working with fault handling in their customer installation. They may also be seen as good examples of how a utility may work with their customers and customer installations to keep the DH system temperatures down. It is possible that more interviews would have resulted in new responses. However, the last interviews did not produce any results that had not already occurred during the previous interviews. This indicated that the study was saturated, and that further interviews might not have contributed to a bigger picture of the issues investigated in this study.

7. Conclusions

This study has investigated how the DH utilities are currently working with fault handling in customer installations in order to reach lower return temperature levels. The study has also investigated what the most frequently reported faults are and how the utilities are working to identify these faults. The main conclusions of the study are described in the bullet list below.

- To obtain low return temperature levels from the customer installations, it is of significant importance to gain physical access to the installations. This gives the opportunity to not only fix minor faults, but also to get to talk to the customer face to face.
- Utilities with low return temperature levels are working close to their customers to obtain a good customer relationship. A common way to obtain this is to have service agreements with the customers or to include free of charge inspections in the DH agreement.
- It is important to create clear incentives to why the customer should work with faults in the installation. The incentives should be easy to understand and combined with substantial information.
- It may be beneficial for DH utilities to help the customer to identify and correct minor faults in the installation. This encourages the customers to contact the utilities the next time there is an issue in the installation which improves the fault detection rate.
- Most of the utilities utilized customer billing data in some way to identify poorly performing substations.
- The most common faults in the customer installations lead to higher flows and/or higher return temperatures.
- The most frequently reported fault categories in the study are leakages and faults in the customers' internal heating system.

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