Fault detection in district heating substations

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HIGHLIGHTS

- High proportion of faults in district heating substations.
- Hourly meter reading can be used to identify faults.
- Automatic meter readings can lead to future proactive fault detection instead of current reactive fault detection.
- Thresholds for fault detection should, if possible, be absolute and not relative.
- Faults are coincidental with no occurrence pattern and thereby difficult to predict.

ABSTRACT

Current temperature levels in European district heating networks are still too high with respect to future conditions as customer heat demands decrease and new possible heat source options emerge. A considerable reduction of temperature levels can be accomplished by eliminating current faults in substations and customer heating systems. These faults do not receive proper attention today, because neither substations nor customer heating systems are centrally supervised. The focus of this paper has been to identify these faults by annual series of hourly meter readings obtained from automatic meter reading systems at 135 substations in two Swedish district heating systems. Based on threshold methods, various faults were identified in 74% of the substations. The identified faults were divided into three different fault groups: Unsuitable heat load pattern, low average annual temperature difference, and poor station control. The most important conclusion from this early study of big data volumes is that automatic meter reading systems can provide proactive fault detection by continuous commissioning of district heating substations in the future. A complete reduction of current faults corresponds to approximately half the required reduction of the current temperature levels in the effort toward future low-temperature district heating networks.

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1. Introduction

All efficiencies in district heating systems with respect to both heat supply and heat distribution increase when lower distribution temperatures are used. With lower distribution temperatures in district heating systems, the possible heat source options will increase with respect to both volume and number in the future heat supply, based mainly on recovered and renewable heat sources. Current high temperatures are a remnant of the conventional fossil fuel-based energy supply in which high temperatures were easy to achieve. Low-temperature heat distribution has been identified as a vital part of future district heating systems [1,2].

Customer heat demands in district heating systems are normally 20 °C to heat buildings and 50 °C for domestic hot water. Current distribution networks have supply temperatures of approximately 75–90 °C and return temperatures of approximately 40–50 °C as annual averages [3]. These levels are used in order to cover the current customer temperature demands but also to compensate for faults in the system. Future system designs currently under discussion include supply temperatures of 50 °C, because customer temperature demands will decrease as customer heat demands decrease in the future. At that point, the margin and acceptance for temperature faults will radically decrease. This implies that temperature faults must be detected quickly.

Since 2015, devices for automatic meter reading have been installed at all substations in Sweden owing to governmental demand for monthly billing of actual heat use. This implies that hourly meter readings for heat, flow, supply and return
temperatures will be available from all district heating substations. These heat meter readings can also be used for the detection of usage, temperature, and control faults appearing in the heat delivery.

1.1. Fault detection

A current preconceived idea is that most heat demands in district heating systems are working well. This paper will show that this is not the case. When running an air handling unit, continuous commissioning is essential to ensure and maintain optimal operation; this is a major conclusion in [4], in which significant work in the area has been analysed. There is no reason to believe that other secondary systems and substations would work for years without any faults occurring. Hence, secondary customer heating systems do not function correctly.

Many fault detection methods described in the literature for district heating application are based on statistical methods—e.g., when a deviation from an expected heat demand is detected [5–9]. These methods require a correct heat demand for comparison. However, a problem is that a large proportion of the substations do not work optimally or even well—it, there are no correct heat meter readings with which to compare.

This paper will provide answers to three research questions to be used when developing fault detection methods for present and future district heating systems.

1.2. Research questions

- What types of faults can be identified in substations?
- What are the proportions of different fault groups?
- What is the proportion of substations that work correctly?

2. Background

District heating systems contribute substantially to a sustainable supply of energy. Heat and electricity can be generated by energy resources otherwise difficult to utilize, such as waste, geothermal heat, and industrial excess heat [3]. In order to remain competitive in the future, there are two major challenges for district heating systems. The first is competition with renewable energy resources and the second is decreased heat demands in new and existing buildings [10].

2.1. Decreased heat demands

In countries with small possibilities to expand district heating delivery due to the saturation of the market, heat demand will decrease in the future owing to energy efficiency measures in the connected buildings, and well-insulated buildings in the future will have essential lower heat demands and will not compensate for the loss in the older buildings [10]. The answer for district heating companies to this scenario can be to identify new applications for district heating and generate more electricity [11]. This could seem contradictory because decreased heat demand ought to result in decreased generated electricity from combined heat and power (CHP) plants, but according to [12], this is not the case because most of the energy decrease will be in heat-only boilers. Another even more important measure in order to maintain the competitiveness in district heating systems is to increase system efficiency. One of the most effective ways to increase efficiency is to decrease distribution temperatures. The advantages of decreased distribution temperatures are lower heat losses, increased efficiency, higher electrical output from CHP plants, and increased utilization of geothermal and solar heat and industrial excess heat [3].

2.2. Distribution temperatures

Current water-based district heating systems—referred to as the third generation of district heating technology with a primary supply temperature of 80–110 °C—are used to heat air to 20 °C and domestic hot water to 50 °C. Why do we need 80 °C to heat air to 20 °C and domestic hot water to 50 °C? (see Fig. 1). There are two reasons why a temperature level of 80/45 °C (supply/return temperature) is necessary. The first reason is that the secondary systems in existing buildings are normally designed for high temperatures. Design supply temperatures have previously been 70–90 °C in Europe. With increasing demand for efficient energy use, the supply temperatures in secondary systems have gradually decreased, and the design temperature in Sweden has been 55–60 °C for the past 30 years [13].

Moreover, it has been shown that both in Sweden and internationally, secondary systems are often oversized [14–18] and are thereby capable of supplying enough heat to provide comfortable indoor temperatures at lower supply temperatures than their design values. The second reason for high primary supply temperatures is the occurrence of temperature faults in substations and secondary systems, and the only option for district heating operators to maintain the heat supply for all customers is to increase the supply temperature.

Heat exchangers and substations do not require these high supply temperatures. If all substations and customer secondary systems worked as designed, current system temperatures could be decreased to approximately 70/35 °C, which was shown in [19]. Hence, the high temperatures in current district heating systems are combinations of old design, convention, and a compensation for temperature faults in substations and secondary systems. These temperature faults are not noticed by customers because buildings are warm and hot water is available from water taps.

For future district heating systems—4GDH with system temperatures of 50/20 °C [1]—the margin for faults will radically decrease because faults will affect customer comfort. This is also one of the main conclusions of a Danish report that evaluated low temperature district heating demonstration projects [20]. In this case, individual limits for differential temperature supervised by continuous commissioning of substations and secondary systems will probably be necessary not only to detect faults quickly but also to make service visits governed by needs rather than—as is common today—by following the calendar in order to avoid spending man-hours checking equipment that is already working well.

2.3. System boundary

District heating systems are often divided into three major parts—heat generation, district heating network, and substations. However, the system efficiency can be optimized only if the system boundary also includes the heated buildings. Faults in secondary systems will be transferred via the substation to the district heating network and heat generation, thus decreasing system efficiency. Hence, customer secondary heat supply systems must be included when addressing the efficiency of district heating systems.

Conventionally, heat generation and distribution have been continuously monitored to detect and solve faults immediately or within a few days, whereas substations have often been regarded as well-functioning as long as customers’ comfort is not affected. Fault detection at the customer end has largely been reactive. This implies that faults which affect customer comfort—rather than faults that decrease system efficiency—are mainly being detected.
2.4. Heat load patterns

Previously, fault detection analysis based on meter readings had to be on an annual basis because that was the available option. In an IEA-DHC report from 2003 [21], it is stated that high-resolution heat meter readings could be used for customer analysis. Still, the analysis of a large number of substations with high measurement resolution is rare. The reason is that, in the past, the collection of heat meter readings has been performed manually and was thus very expensive. In a thesis from 1996 [22], the heat load patterns of 50 substations were analysed with a measuring resolution of 15 min during a period of 18 months to learn more about heat demands in buildings. The lack of knowledge regarding the actual performance was the reason for the analysis of one building in [23] in which a resolution of 5 min was used. A method to separate domestic hot water from space heating using existing heat meters is presented in [24] and is interesting from a heat load pattern perspective.

2.5. Excuses for not working with fault detection in substations and secondary systems

Energy companies have historically put significant effort into improving the efficiency of energy supply and distribution. In the district heating field, heat supply plants and networks have not only been improved but also continuously supervised in order to detect faults quickly and eliminate detected faults. However, substations and customer secondary systems have been of less interest. They have been regarded as the customers’ problem. If only customer comfort is taken into consideration, this is a working strategy; but from a system efficiency and competitiveness perspective, it is not.

Reasons for not working with fault detection in substations and customer secondary systems are—in the first place—probably because there are so many and significant work is required to see any results. A large number of different possible faults can occur unsystematically [25–27]. In a 2005 report [28], three major reasons were identified why work to improve efficiency was not performed—lack of knowledge, internal problems with handling a job in which a large part of the company must be involved, and difficult customer relations in which technical personnel adopt a sales role and sales personnel become involved in technical discussions.

The only way to override the above mentioned problems is to start working with hidden faults. The same report provides advice on how to manage the problems—e.g., split the work into small projects, label the projects as system efficiency projects so that people understand that they affect the whole district heating system, decide how customer contacts should be realized, and—if possible—involve the customer and even see that they pay for part of the investment.

Another problem is that when work has been performed to decrease system temperatures, it has often been organized as a campaign. Because new faults will appear in substations and secondary systems, work to decrease system temperatures must be an ongoing component of day-to-day work. Otherwise, system temperatures will slowly increase as new faults appear.

2.6. Current faults

Faults in substations and secondary systems can be divided into three categories. First, there are faults resulting in comfort problems such as lack of heat or domestic hot water and physical faults such as water leakage or sound emissions. Second, there are faults that are known but unsolved due to the need of too many man-hours to identify them. Finally, there are faults for which new fault detection methods must be developed. The third category includes faults caused by human factors such as faulty settings in building operating systems. This paper addresses only the last two categories. In order to identify and solve faults in the last two categories and thereby increase system efficiency, continuous commissioning of substations and secondary systems is necessary. Fault detection can then go from being reactive to becoming proactive.

2.7. Introduction of automated meter reading systems

On 1 July 2006, a change in the Swedish law [29] required that, effective 1 July 2009, electrical providers charge customers for their actual use of monthly electricity rather than basing their charges on prior usage as they did before. To fulfill this demand, automatic meter reading systems were installed in the electric grids but also in the district heating systems, because a major part of the district heating systems in Sweden are operated by companies that also operate the electric grids. Since 1 January 2015, it is
also mandatory for district heating companies to charge their customers for the actual use of district heating [30]. Even though the demand is for monthly readings, the automatic meter reading systems are designed for a resolution of one hour or higher—i.e., hourly meter readings at all district heating substations can be available in 2015 in Sweden, and these meter readings could be used for fault detection purposes.

The literature review in this paper has an overrepresentation of Swedish references owing to 30 years of unique Swedish research programmes in the district heating field.

3. Method

3.1. Gathered data

The datasets in this study come from the automatic meter reading systems in two district heating systems in the south of Sweden—Helsingborg, with approximately 10,000 connected substations and an annual heat supply of 3.6 PJ, and Ängelholm, with approximately 3000 connected substations and an annual heat supply of 0.7 PJ. The average annual supply temperature in 2010 in Helsingborg was 83.8 °C and in Ängelholm was 85.8 °C. The corresponding return temperatures were 46.9 °C in Helsingborg and 47.8 °C in Ängelholm From the two district heating systems, meter readings from 135 substations were selected for analysis—82 from Helsingborg and 53 from Ängelholm (see Table 1). The datasets are the same as in [31], apart from six substations that were excluded owing to incomplete datasets. All datasets are hourly meter readings of heat, flow, supply, and return temperatures on the primary side of the substation during one year. All datasets are from 2010, 1 January through 31 December.

The selection is based on the amount of annually delivered heat and customer category. In the customer records, customers are divided into eight customer categories because of governmental demand to report energy use statistics. The energy statistics contain six customer categories: industrial demands, one- and two-family dwellings, multi-dwelling units, ground heating, public administration, and others. In the customer records, the resolution is higher in two cases; in the customer records, public administration is split into health and social care buildings and public administration buildings. Others in the statistics are split between trade buildings and others. In this study, the customer category of one- and two-family dwellings has been excluded because of their low share of the total heat demand (~20%) split among a large number of substations—i.e., each substation in a one- and two-dwelling building has a very small impact on total system efficiency. Ground heating and others from the customer records are also excluded—ground heating because it comprises only single installations and others because the subscriptions are undefined and therefore impossible to evaluate. The customer categories from which the analysed substations originate include approximately 3000 of 13,000 total substations existing in the two district heating systems. From each customer category, the substations with the highest volume of annual heat delivery were selected.

3.2. Analysis

In this study, meter readings from substations are analysed manually. It is a theoretical analysis, but it is based on meter readings observed from real substations in continuous operation. Three types of faults or symptoms of faults have been identified:

- Unsuitable heat load pattern.
- Low average annual temperature difference.
- Poor substation control.

3.2.1. Unsuitable heat load pattern

In order to identify unsuitable heat demand patterns, the activity in the building has to be known. In this study, the information can partly be found in the customer records by using the customer categories, but there are two major problems. First, the information is manually inserted into the customer records and there is a risk of error. Single errors have been discovered but are of a different magnitude than unsuitable heat load patterns. Second, the customer categories are set for reporting statistics and are only partly suited for determining expected heat load patterns—e.g., multi-family dwellings, which is the most homogeneous customer category whereas public administration buildings is a heterogeneous group. The heat load patterns used in this study are continuous, night setback (NSB), time clock operation 5 days a week (TCO5), and time clock operation 7 days a week (TCO7). The heat load patterns are studied as an average for four seasons. The heat load patterns and seasons are defined in [31]. The selection criteria for unsuitable heat load patterns in this study are all multi-family dwellings that do not have a continuous heat load pattern, industrial demands that do not have TCO5, and commercial buildings that do not have any time clock operation of ventilation at all. All buildings with pronounced NSB control are also considered as unsuitable heat load patterns.

Health and social services buildings are mainly owned by county councils and can be anything from hospitals with 7–24 operation with an expected continuous heat demand to an office building with an expected TCO5 heat load pattern. Public administration buildings are municipal building—e.g., schools, gymnasiums, public baths, libraries with daytime activity—but could also be service buildings for elderly people. Thus, health and social service and public administration buildings are impossible to evaluate for unsuitable heat load patterns apart from NSB because of their heterogeneous heat load patterns.

3.2.2. Low average annual temperature difference

The average annual temperature difference is calculated from meter readings for delivered heat and flow on an annual basis. The best substation in this study, from a temperature difference perspective, has a temperature difference is just below 55 °C. An average annual supply temperature of 85 °C corresponds to an annual average return temperature of 30 °C. This level is what is possible with today’s technology. However, because the perfect building and substation do not exist and all district heating customers have individual heat demands, a threshold had to be defined for average annual temperature difference that is good enough as a general value. In the analyses, substations were divided into groups depending on average annual temperature difference (one group for every 5 °C; see Table 4). This threshold was set at the upper two 5 °C groups. It would be preferred to have

Table 1

<table>
<thead>
<tr>
<th>Customer categories</th>
<th>Number of substations</th>
<th>Annual heat demand [TJ]</th>
<th>Total</th>
<th>Average</th>
<th>Lowest</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-dwelling buildings</td>
<td>35</td>
<td>220.7</td>
<td>6.3</td>
<td>2.9</td>
<td>15.6</td>
<td></td>
</tr>
<tr>
<td>Industrial demands</td>
<td>33</td>
<td>68.9</td>
<td>2.1</td>
<td>0.2</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Health and social services buildings</td>
<td>10</td>
<td>17.2</td>
<td>1.7</td>
<td>0.5</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>Commercial buildings</td>
<td>22</td>
<td>63.8</td>
<td>2.9</td>
<td>0.3</td>
<td>14.2</td>
<td></td>
</tr>
<tr>
<td>Public administration buildings</td>
<td>35</td>
<td>147.5</td>
<td>4.2</td>
<td>0.4</td>
<td>27.0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>135</td>
<td>518.0</td>
<td>3.8</td>
<td>0.2</td>
<td>27.0</td>
<td></td>
</tr>
</tbody>
</table>
individual limits for low average annual temperature difference for each building; however, owing to lack of knowledge of each customer’s prerequisites, this is impossible. Thus, an average annual temperature difference exceeding 45 °C is regarded as good enough in this paper.

The calculations are based on a constant density of 990 kg/m³, corresponding to a return temperature of 45 °C, because the flow meter is normally mounted in the return pipe. The heat capacity factor used is 4.18 kJ/kg·K, corresponding to a temperature of 65 °C, which is the average of supply and return temperatures. Low average annual temperature difference is a symptom of faults rather than a fault, and it belongs in fault category two or three.

3.2.2. Poor substation control

Abnormal heat demand indicating poor substation control is manually analysed from four different diagrams for each substation—heat power signature for daily and hourly averages and weekly analysis of energy and flow. Two selection criteria were identified—major irregular oscillations and bad correlation between heat demand and outdoor temperature. In Fig. 2, an example of a multi-dwelling building with irregular oscillations in energy and flow is presented, and the heat power signature for hourly averages show a bad correlation between heat demand and outdoor temperature. Fig. 3 shows a multi-dwelling building that works correctly. Poor substation control is—just as low average annual temperature difference—a symptom of fault rather than a fault and belongs in fault category two or three.

4. Results

Heat demand is unique for each building. This is an aggravating circumstance in fault detection for district heating substations because of the difficulty in separating deviating heat demands from normal heat demands. Three fault groups are identified by manual analysis, but they could easily be automated; this is a prerequisite for future district heating systems in order to maintain competitiveness.

In Table 2, a summary of the results from the analysis of the 135 substations can be found. One hundred (74%) of the analysed data-sets show faults or symptoms of faults in substations or secondary systems. The most common is low average annual temperature difference with 92 (68%) followed by unsuitable heat load pattern, which is identified in 30 (22%) of the substations. Poor substation control was identified in 16 (12%) of the substations. Only 35 (26%) work correctly—i.e., have a large temperature difference and proper control and seem to have a correct heat load pattern. Health and social services buildings and public administration buildings were not evaluated for unsuitable heat load patterns. For the remaining 90 substations, 22 (24%) are regarded as well-performing substations.

The result shows a large number of faults in the substations but little or no correlation between different types of faults. All fault groups are identified in all customer categories, and no systematic faults can be identified.

4.1. Unsuitable heat load pattern

The heat load patterns used in this study were continuous, NSB, TC05, and TC07. The heat load patterns for the five customer categories were identified (see Table 3). Depending on the activity in the buildings, different heat load patterns are expected. Health and social services buildings and public administration buildings are very heterogeneous from a heat load pattern perspective; so, apart from the four substations with NSB control, they are impossible to evaluate without knowledge of the activity in each building.

Thirty-five substations (shaded in Table 3) with unsuitable heat load patterns were identified out of 90 analysed substations—i.e., almost 40% of those in the three customer categories of multi-family dwellings, industrial demands, and trade buildings. A drawback in terms of identifying unsuitable heat load patterns is of course that the expected suitable heat load pattern in this study is set as a general pattern for all customer categories rather than individually for each building as it should be. However, unsuitable heat load pattern—the second most common fault—is easily identifiable and simple to correct.

4.2. Low average annual temperature difference

For decades, it has been well known that a large temperature difference is advantageous; however, many substation temperature differences in district heating systems are low. In this study, the average annual temperature difference has a range from 7 to 54 °C. In Table 4, the 135 substations are divided by customer category and intervals of average annual temperature difference.

Almost 70% of the substations have a temperature difference of ≤45 °C, and 15% have one less than 30 °C. Only 7% of the substations have a temperature difference exceeding 50 °C.

All customer categories contain substations with both large and small temperature differences, which indicates that it is a general problem. Hence, low average annual temperature differences are not systematic faults associated with customer category but rather have individual explanations in each substation; this conclusion was drawn in a 1987 study [25].

4.3. Poor substation control

Poor substation control has been identified in all customer categories and all temperature difference intervals. Out of 135 substations analysed, 16 (12%) were identified to have poor substation control (see Table 5). Four substations had a bad correlation between heat demand and outdoor temperature. All of them also had irregular oscillations.

No general correlation between poor substation control and low average annual temperature difference can be identified, but the substations with a temperature difference of <30 °C are overrepresented in poor substation control (see Fig. 4).

5. Discussion

In the fourth generation of district heating systems, 4GDH, 50 °C supply and 20 °C return temperature are discussed. A reduction of system temperatures increases system efficiency with reduced cost and emissions as a result. Today faults can be—and are—compensated by increased system temperatures. This study has shown that the district heating system does not work correctly. Almost 3/4 of the analysed substations in this study would be considered to have some kind of fault. The distribution temperatures in the two district heating systems in which the analysed substations are situated, Helsingborg and Angelholm, are in the midrange of district heating systems in Sweden. This makes it probable that the results are representative of at least Swedish conditions. In 4GDH systems, today’s faults will be unacceptable. In this study, all analyses are performed manually. However when applied in district heating systems to identify and eliminate faults quickly, automatic fault detection in the form of continuous commissioning in one way or another will become necessary.

The quality of the present customer records, automatic meter reading systems, substations, and secondary systems are not better than what is needed for today’s DH systems. To be able to introduce 4GDH, all system parts mentioned must be improved. A
difficulty with respect to fault detection in district heating substations is that there are large variations between well-performing substations. Different customers have different heat demands and different heat load patterns. A normal heat demand for one customer is abnormal for another.

To implement fault detection in district heating systems, district heating companies must have a large amount of knowledge about their customers and their behaviour on an individual level from a heat demand perspective. It is also necessary to include the customer secondary heating systems in the optimization of a district
heating system, and work must therefore be performed in close cooperation with the individual customers. To begin, general thresholds can be used; but in the long run—for fourth-generation district heating systems—thresholds for fault detection probably must be set on an individual basis. Many methods found in research literature are based on identifying deviation from previous heat demands; but if 75% of the substations are already more or less faulty, this does not work. This is why fault detection based on absolute thresholds rather than relative thresholds is preferable.

5.1. Heat meter issues

This study shows that hourly resolution for meter reading is sufficient. The amount of faults is, at present, so large that increased resolution is of no use. For 4GDH, a higher resolution might be necessary; however, there might also be a demand for a higher-quality meter readings.

Conventionally, heat meter readings have been used only for billing purposes. The reason for measuring has been to split the cost for a common heat supply system in such a way that the customers regard as fair. The driving force for developing heat meters has been low prices. If heat meters are to be used for fault detection in the future, there might be other demands. Development areas for heat meters could be increased accuracy of sensors and measurement systems but also additional parameters that should be measured other than heat, flow, supply, and return temperatures. For instance, secondary temperatures and flows or differential pressures in both primary and secondary systems could be of

### Table 2
Summary of the 135 analysed substations split into identified faults and well-performing substations for five customer categories.

<table>
<thead>
<tr>
<th></th>
<th>Multi-family dwellings</th>
<th>Industrial demands</th>
<th>Health and social services buildings</th>
<th>Trade buildings</th>
<th>Public administration buildings</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of substations</td>
<td>35</td>
<td>33</td>
<td>10</td>
<td>22</td>
<td>35</td>
<td>135</td>
</tr>
<tr>
<td>Unsuitable heat load pattern</td>
<td>4</td>
<td>23</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>39</td>
</tr>
<tr>
<td>Low annual average temperature difference</td>
<td>19</td>
<td>27</td>
<td>9</td>
<td>18</td>
<td>19</td>
<td>92</td>
</tr>
<tr>
<td>Poor substation control</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Well-performing substations</td>
<td>15</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td>Proportion of well-performing substations</td>
<td>43%</td>
<td>9%</td>
<td>10%</td>
<td>18%</td>
<td>34%</td>
<td>26%</td>
</tr>
</tbody>
</table>

\* Health and social services buildings and public administration buildings are regarded as having unsuitable an heat load pattern only if NSB is applied owing to the heterogeneous heat load pattern for these two customer categories.

### Table 3
Analysed substations sorted by four heat load patterns and five customer categories. Shaded numbers are identified as substations with unsuitable heat load patterns.

<table>
<thead>
<tr>
<th>Heat load pattern</th>
<th>Multi-family dwellings</th>
<th>Industrial demands</th>
<th>Health and social services buildings</th>
<th>Trade buildings</th>
<th>Public administration buildings</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td>31</td>
<td>17</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>74</td>
</tr>
<tr>
<td>NSB</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>TCO 5</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>6</td>
<td>17</td>
<td>34</td>
</tr>
<tr>
<td>TCO 7</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>8</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>33</td>
<td>10</td>
<td>22</td>
<td>35</td>
<td>135</td>
</tr>
</tbody>
</table>

### Table 4
Analysed substations sorted by six average annual temperature difference intervals and five customer categories.

<table>
<thead>
<tr>
<th>Annual average temperature difference</th>
<th>Multi-family dwellings</th>
<th>Industrial demands</th>
<th>Health and social services buildings</th>
<th>Trade buildings</th>
<th>Public administration buildings</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30</td>
<td>5</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>30–35</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>36–40</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>9</td>
<td>4</td>
<td>26</td>
</tr>
<tr>
<td>41–45</td>
<td>10</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td>46–50</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>13</td>
<td>33</td>
</tr>
<tr>
<td>&gt;50</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>33</td>
<td>10</td>
<td>22</td>
<td>35</td>
<td>135</td>
</tr>
</tbody>
</table>

### Table 5
Sixteen out of 135 analysed substations were observed to have bad substation control based on selection criteria.

<table>
<thead>
<tr>
<th>Poor substation control</th>
<th>Multi-family dwellings</th>
<th>Industrial demands</th>
<th>Health care and social service buildings</th>
<th>Trade buildings</th>
<th>Public administration buildings</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irregular oscillations only</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Irregular oscillations and bad correlation between heat demand and outdoor temperature</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>16</td>
</tr>
</tbody>
</table>
interest. A part of this already exists in building supervision systems. Then, it is a matter of how to utilize the meter readings and by whom it should be accomplished.

This study shows that hourly meter readings can be used for fault detection in district heating substations that previously would demand great effort in man-hours. It further enables continuous commissioning that can change service visits to be governed by demand rather than by calendar.

6. Conclusions

This study of meter readings from 135 district heating substations was performed in order to identify faults. In the present district heating systems, the proportion of faults is high. From the 135 meter reading data sets, 100 were identified to have faults—i.e., only 26% of the analysed substations worked correctly. Three main groups of faults were identified—unsuitable heat load pattern, low average annual temperature difference, and poor substation control.

6.1. Unsuitable heat load pattern

Unsuitable heat load patterns result from faulty settings in a building’s control systems—i.e., not a fault in the equipment but rather caused by human factors. It is a fault in the building’s control system and not in the substation. According to this study, the proportion of unsuitable heat load patterns is in the range of 30–40%; however, these faults are easy to identify and simple to correct. This fault group is probably the easiest to address among all measures to decrease heat use in buildings.

6.2. Low average annual temperature difference

Approximately 70% of the substations have a temperature difference of less than 46°C. Low average annual temperature difference is one of the most important factors working against high efficiency in substations and has been an improvement issue in district heating discussions for decades, but it is obviously still a serious issue.

6.3. Poor substation control

Poor substation control was identified in 14% of the substations. With respect to low average annual temperature difference, poor substation control is not a fault but rather a symptom of faults that can be either physical or caused by human factors. Moreover, it can be present in the substations or the secondary systems. However, there is little or no correlation between a low average annual temperature difference and poor substation control.

6.4. Overall conclusions

An aggravating circumstance for fault detection in substations and customer secondary systems is that heat demand patterns in buildings are distinct. A correct heat demand for one building constitutes a fault in another building.

This study has shown that hourly meter readings can be used to identify faults in district heating substations and customer secondary systems. From the three fault groups, low average annual temperature differences are still—after decades of discussion—the most important problem to address in order to improve the system efficiency in district heating systems. However, unsuitable heat load patterns are probably the fault that is the easiest and most cost-effective to address. Generally speaking, all faults are coincidental and have no occurrence pattern; thus, they are difficult to predict. The most important conclusion from this study is that automatic meter reading systems can lead to future proactive fault detection instead of current reactive fault detection in district heating substations and secondary customer systems. This conclusion is vital for the competitiveness of current district heating systems but is a necessity for future low-temperature district heating systems.

Compared to current distribution temperature levels, elimination of faults would result in half the decreased temperature level necessary for future district heating systems. The other half must be achieved in customer heating systems.

In this study, all analyses were manually performed for the purpose of research. However, automated methods must be developed in order to apply these analyses in district heating systems. The main conclusions from this study can then be utilized when designing appropriate data mining methods.

Acknowledgement

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References


![Fig. 4. Proportion of total amount of analysed substations (in blue) and proportion of poor substation control (in red) for six different temperature difference intervals.](image)


Laulen burg P. Improved supply of district heat to hydronic space heating systems. Doctoral thesis. Lund University, Lund; 2009.


