4.3. ML perspectives in the context of DH

Inspired by the successful integration of ML in many other areas, it is beginning to draw attention in the DH sector as well. Albeit only few examples of actual application of ML in the context of DH exist today, it has an obvious potential as a component of tomorrows heating networks that can be integrated through the fast and inevitable development leading to the digitalization of the supply systems.

One of the large potentials of ML is **to predict heat loads** from the expanding data bases of customer data and operational data in combination with weather forecasts, national holidays, weekday, etc. to optimize and plan the heat production, thereby lowering heat loss and handling peak loads. In combination with economic data, prices of electricity, gas, etc., as well as integration of sustainable energy, which is not always reliant/constantly available, it will also be an efficient tool when integrating DH with the remaining energy sectors to optimize the overall use of resources, both environmentally and economically. This is of even higher interest, when more sustainable energy is integrated into the market, since electricity is not always needed, when the wind is blowing.

Another large potential is to use intelligent algorithms in **fault detection** on the basis of retrieved customer data and other data from the network. For example, such a tool will be able to identify leakages, inefficient heating systems or errors stemming from failure related to single components. It can thus apply both at the scale of individual components and the overall installation where it can be associated with the operation and settings of the sub-station. Based on real-time remote reading of smart meters distributed in the customer network, the software will typically be able to monitor data on the fly and significantly reduce the time passed from a fault appears to its detection and repair, which has until now been based on manual inspection.

Manual inspection is a time-demanding activity, and because of this, substations with the largest heat demand in the DH system are normally prioritized when performing the analysis, leading to a large share of poorly performing substations going unnoticed. Accumulating over the full DH network, this could have a significant effect on the energy efficiency. Identifying and correcting many small problems in a DH area can potentially help save energy and improve performance of the production facility.

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4.4. Pioneering examples of exploitation of ML in DH

In Denmark, Sweden and several other countries, many smart meters are currently being installed or will be installed in the near future. Databases hosted by the major supply companies or at service companies and facilities comprising customer data with supply- and return temperatures, flow and energy consumption, typically with an hourly readout, already exist. Together with local weather information and forecasts, this pool of data has started to attract attention in the light of optimization. Methods have been demonstrated addressing how the information can be exploited together with ML and statistical methods for more than the original purpose of billing.

4.4.1. Heat demand prediction

The use of ML algorithms to predict heat demand has been intensively investigated in the buildings- and electricity sectors but are also strongly progressing in DH. Artificial Neural Networks (ANN) and Support Vector Machines (SVM) are two of the most widely used techniques [4][5], but also, e.g., Decision Trees (DT) are suitable to forecast energy consumption in the context of DH [6].

Recently, E. Saloux et al. [6] found that ML algorithms, including Decision Trees (DTs), can significantly improve the accuracy of predicted heat loads by incorporating the effect of additional influencing factors (e.g., time of the day, day of the week, solar radiation, etc.). Potential implementation of such models in this example is highly desirable to control integrated heat storage and solar thermal collectors to optimize the overall energy efficiency.

Integration of national and school holidays into ML models have also shown improvements in the predictions [7] and may be considered to optimize forecast models.

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4.4.2. Fault detection.

S. Farouq et al. [8] performed an analysis of outliers among smart meter datasets from 800 multi-dwelling buildings by calculating and comparing a defined parameter that estimated the thermal energy demand response with respect to change in outdoor temperature. The strength of the relation between energy demand and outdoor temperature was shown to hold important information about operational efficiency of a substation. It was concluded that a robust regression method in combination with the ordinary least square's method can provide reliable estimates on the operational efficiency of DH substations.

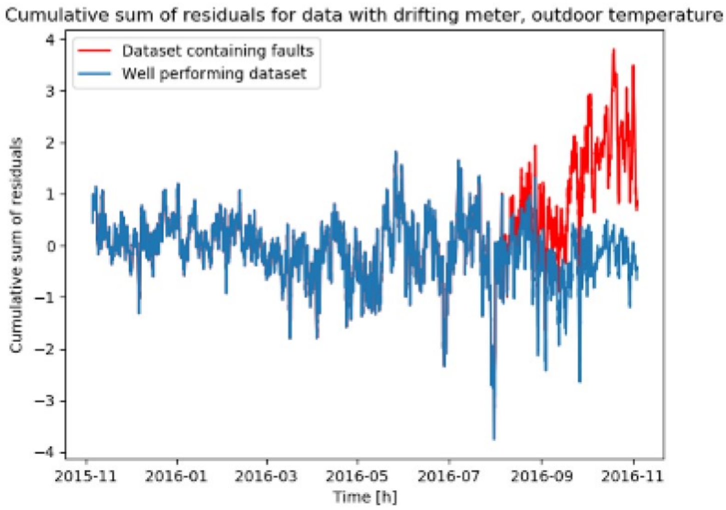

Figure 2 Identification of an artificially induced fault on a single sub-station by ML-prediction of the mass flow.

Source: Figure adapted from [9] under the Creative Commons Attribution-NonCommercial-No Derivatives License (CC BY NC ND)).

In a different approach, S. Månsson et al. [9] demonstrated a ML approach to fault detection using smart meter values recorded hourly during one year from a substation in Sweden. They showed that prediction of the flow and deviations from predicted values could be effectively used to spot artificially induced faults that were made up to mimic e.g. valves that are stuck, fouled heat exchanger areas in the heat exchanger and malfunctioning temperature transmitters, but also wrong settings in the control system.

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4.4.3. Intelligent control

In general, the application of intelligent control in DH is a promising technology that is currently receiving strong attention, both from the side of production companies and in relation to supply. For example, digitalization was a highly present theme at the DH and cooling conference DHC2018 held in Hamburg Sept. 2018 (https://www.dhc2018.eu/).

Furthermore, in the EU H2020 project STORM [10-12] the aim is to develope a specific controller that enables DH suppliers and distributors to maximize the use of waste heat and renewable energy sources in DHC networks. This action incorporates the use of ML and the results have been applied at two demonstration sites in Sweden and the Netherlands.

During recent years, Danish Technological Institute (DTI) has been working with ML in several contexts. In activities focusing on DH, DTI is currently receiving support from the national DH association Dansk Fjernvarme (https://www.danskfjernvarme.dk/english) to promote a smaller project on utilization of smart meter data for optimization purposes by means of ML. Encouragingly, DTI was recently given the opportunity to present the project at the annual meeting in October 2018 of Dansk Fjernvarme [13], gathering participants from the approximately 400 individual Danish DH companies, and found a strong interest. Especially small and medium-sized companies not having the resources needed to perform an extensive analysis of data themselves were interested in the future outcome of these activities.

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