Improved Interfaces for Enabling Integration of Low Temperature and Distributed Heat Sources – Requirements and Examples

Natasa Nord[1], Dietrich Schmidt[2], Anna Kallert[2], Svend Svendsen[3]

[1]*Norwegian University of Science and Technology, Department of Energy and Process Engineering, NO-7491 Trondheim, Norway*

[1]natasa.nord@ntnu.no

[2]*Fraunhofer Institute for Building Physics, Department Energy Efficiency and Indoor Climate Gottschalkstrasse 28a, DE-34127 Kassel, Germany*

[2]dietrich.schmidt@ibp.fraunhofer.de

[3]anna.kallert@ibp.fraunhofer.de

[3]*Building Energy Section, Department of Civil Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark*

[4]ss@byg.dtu.dk

Abstract

By introducing better interfaces between the demand and supply, district heating and cooling (DHC) systems can be transformed into a smart grid energy system on a district level. In the IEA DHC Annex TS1 project, the Subtask C collects and identifies promising models, concepts, and technologies to meet the goals of future renewable based community energy systems. The problem of the improved interfaces in DHC may be explained via hard and soft issues. The hard issues cover the following: DHC network structures, requirements for consumer substations and buildings, and connection principles for distributed energy sources. The soft issues cover the following: technical and economical modelling of the distribution system, optimization between demand and generation side, innovative control concepts and energy measurement, transition of the existing DHC grid to the LTDH grid, and new pricing and business models. The article aims to provide an overview on the necessary measures to enable transition to the LTDH. Several examples with successful utilization of waste and solar heat for the district heating purpose are shown. Connection principles and strategies to decrease the return temperature are shown. To enable continuously a desired level of the return temperature, fault detection and diagnosis are necessary in both DHC network and consumer substations. Good fault detection and diagnosis require advanced monitoring system and smarter heat grids, especially in substation interfaces. Developing new pricing models is essential to promote sustainable development of LTDH systems. Necessary measures to enable higher market share for waste and solar heat are suggested.

Keywords - district heating system, consumer substations, control, heat price

1. Introduction

Low temperature district heating (LTDH) can substantially reduce total greenhouse gas emissions, increase reliability of the energy systems, enable transition to the renewable energy society, and secure energy supply for future development of society.

LTDH can increase the integration of renewable and waste energy sources and may significantly contribute to the overall efficiency of the future energy systems. Communication and acceptance barriers as well as cost issues and business concepts are still challenging issues for the district heating. By introducing better interfaces between the demand and supply, district heating and cooling (DHC) systems can be transformed into a smart grid energy system on a district level. In the IEA DHC Annex TS1 project, the Subtask C collects and identifies promising models, concepts, and technologies to meet the goals of future renewable based community energy systems. Interfaces in DHC systems context present different type of links between energy supply and demand of buildings by means of water-based systems. The area of the DH interfaces covers a broad range of issues as shown in Fig. 1.

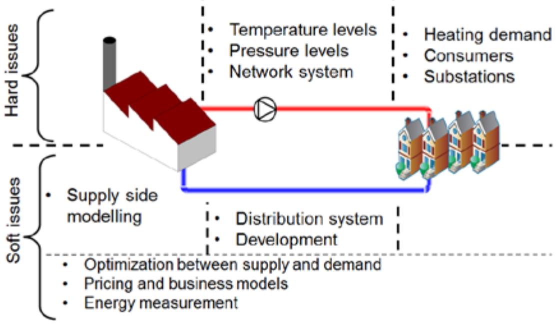

Fig. 1. Big picture of interfaces in district heating systems

The interfaces issue is highly relevant for a successful implementation of the LTDH and thereby enabling transition to the renewable energy society and secure energy supply for future development of society. The problem of the improved interfaces in DHC may be explained via hard and soft issues. The hard issues cover the following topics: DHC network structures, requirements for consumer substations and buildings, and connection principles for decentralized energy sources. The soft issues cover the following topics: technical and economical modelling of the distribution system, optimization between demand and supply side, innovative control concepts and energy measurement, transition of the existing DHC grid to the LTDH grid, and new pricing and business models. The article aims to provide an overview on the mentioned issues necessary for transition to the renewable based community energy systems.

Several examples with successful utilization of waste and solar heat for the district heating purpose are shown. A new actor at the DHC market, prosumer, is introduced.

Distribution and development issues are presented. In order to decrease the distribution losses, temperature levels have to be decreased. The easiest way to start with this is to firstly decrease the return temperature. To enable continuously a desired level of the return temperature, fault detection and diagnosis (FDD) are necessary in both DHC network and consumer substations. Good FDD require advanced monitoring system and smarter heat grids with a higher intelligence content, especially in substation interfaces. Overview of the most common faults are given together with the research activates and business examples for smart monitoring.

Developing new pricing models is essential to promote sustainable development of LTDH systems. Necessary measures to enable higher market share for waste and solar heat are suggested.

2. Predicting DH demand and future developement

Energy efficiency in buildings has been an important topic since 1970 and has been widely recognized as an option to decrease energy use. For that purpose, different tools, methods, standards, and business models have been developed [1]. The directive on the energy performance of buildings (EPBD) recast established the political target of nearly zero energy buildings (nZEB) for all new buildings by January 2021 [2]. The topic of zero energy buildings (ZEB) has been important in the last years [3-7]. nZEB and ZEB have to be actively connected to the energy systems to fulfill their requirement. Regardless of the energy requirements for new buildings, most of today's buildings are existing buildings. Therefore, energy planning and management of the future integrated energy systems has to include a variety of different buildings. Due to different building purposes, occupant behavior, and operation and maintenance, building energy use is a complex system with emergent behavior [8]. Therefore, forecasting future building heating demand should be based on stochastic methods [9] and combination of statistical and physical methods [10].

Analysis on development of the heating demand until 2050 was made based on the Norwegian building statistics of the current residential building stock and forecasts for the residential building development in Norway found in [11]. The aim of the analysis was to show change in total heat demand due to energy efficiency in buildings and market penetration of the new houses. Based on the current statistics, there are 61.7 % of older buildings, 35.1 % of intermediate buildings, and 3.1 % of low energy buildings, and 0.1 % of passive houses. Linear models for the building stock development were assumed based on [26] and given in Fig. 2. An imaginary area presenting a residential building stock with a heat demand of 80 MW was introduced.

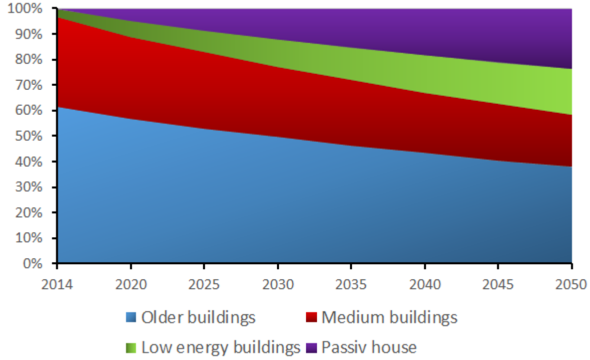

Fig. 2. Forecasting of the building stock development in Norway

By using the results on the heat demand, explained in [12] and linear models for the building stock development shown in Fig. 2, a projection of the heat demand development until 2050 was obtained as shown in Fig. 3. In addition, Fig. 3 gives heat demand in the case of ambitious and conservative development of the building stock. A change of ± 20 % deviation of the normal development, given in Fig. 2, was introduced to produce ambitious and conservative development, respectively.

From Fig. 3 it may be concluded that even with the ambitious scenario for the residential building development, the total heat demand would decrease by about 18 % in 2050 compared to the current heat demand. This means that the DH would still be needed for most of the buildings in 2050. Based on this, the LTDH would be a promising heat technology in 2050. It should also be noted that in Fig. 3, increase of the building numbers was not counted, which could increase the total heat demand.

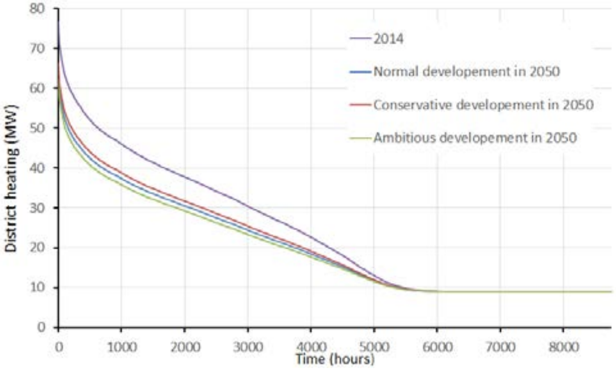

Fig. 3. Heat demand development for the residential building stock in Norway

In the analysis in Figs. 2 and 3, market penetration of nZEB was not included. However, some studies show that the excess heat from nZEBs can benefit DH systems by decreasing the production from the centralized units [4]. Research on the distribution and investment issues of the DH systems show that the most favorable conditions for the further development appear in large cities and there is low risk for reduced competitiveness due to reduced heat demand. Hence, reduced heat demands are not barrier for DH in the future [12]. Regarding, energy sources for the DH in the future, a thorough research on sustainable heat potentials at the European level shows that there is enough available heat, but policy measures are necessary for realization of all the potentials [13].

3. Distribution and developement issues

One of the main idea of the LTDH is to enable easy integration of the renewable distributed energy sources. Renewable energy and waste heat sources together with heat storages may be organized as decentralized or distributed. Decentralized systems imply that heat supply is divided into several plants geographically decentralized, but centrally organized. The situation with distributed energy sources will appear when single buildings, industrial plants, and any other actors are enabled to deliver their renewable or waste heat to the DH system. To enable a well-functioning and renewable

DH system with many actors, good knowledge on district heating heat losses and requirements for the grid connection are highly necessary.

3.1. Heat losses and pipe reliability issues

Reliable distribution system is highly necessary to realize the ideas of the LTDH and stay competitive on the energy market. Therefore, knowledge on the heat losses and pipe reliability is highly necessary.

It has been difficult to identify high quality data on heat losses in the DH systems. Some pipe producers provide small calculation programs to calculate heat losses in pipes. However, these data are valid only for the design conditions. A methodology for the pipe network cost models including pipe heat losses and heat density has been suggested in [14]. Statistical data on the heat losses provided from the branch organizations and on the national level does not give a good indication how operation and temperature levels may contribute to the distribution losses. Usually, heat distribution losses as a function of linear heat density, Fig. 4, may be found. By using statistical data from Danish DH plants, it was possible to give relationship between the heat losses and delivered heat, as in Fig. 5. The main conclusions from the available data on the heat losses in the DH is that smaller DH plants and low linear heat density induced higher heat losses in percentage.

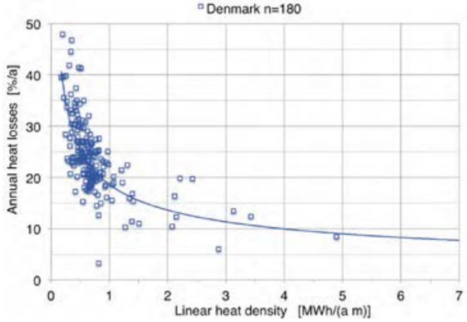

Fig. 4. Heat distribution losses as function of the linear heat density in Denmark for plants

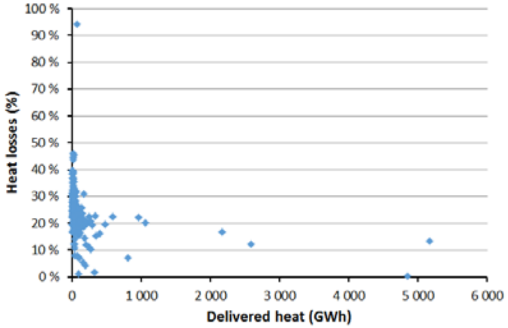

Fig. 5. District heating heat losses for separate plants in Denmark

Regarding pipe reliability of the DH network, a thorough review identifies and classifies the most relevant factors leading to pipe deterioration as shown in Table 1 [15]. A good database should include well organized data shown in Table 1. Implementation of new IT-technologies should enable this.

Table 1. Factors leading to water system deterioration

Physical factors	**Environmental factors**	**Operational factors**
Pipe age and material	Pipe bedding	Internal water pressure
Pipe wall thickness	Trench backfill	Leakage
Pipe vintage	Soil type	Water quality
Pipe diameter	Groundwater	Flow velocity
Type of joints	Climate	Backflow potential
Thrust restraint	Pipe location	Operational and maintenance practices
Pipe lining and coating	Disturbances	
Dissimilar metals	Stray electrical currents	
Pipe installation	Seismic activity	
Pipe manufacture		

3.2. Integration of renewable energy sources

To enable transition to the renewable energy society and secure energy supply for future development of society, integration of distributed energy systems is highly necessary. This will induce a new actor at the DH market called “prosumer” [16] that may be treated as third party access. A customer that both produces and consumes heat from DH is called prosumer. This concept offers great opportunities for successful utilization of solar heat into the DH and supports the transition to smart thermal grid. The concept of “prosumer” is already known from application in power sector [17, 18]. In the DH context, this will imply that customers may have possibility to deliver excess heat from distributed renewable energies (e.g. solar heat, heat pumps, and waste heat) to the DH network. There are different approaches for the prosumer connections, depending on the DH network temperature level, delivered heat temperature level, and building requirements. Prosumer may deliver their heat into the supply or return line. Export of excess heat from the cooling machines (CM) to the DH network are shown in Fig. 6.

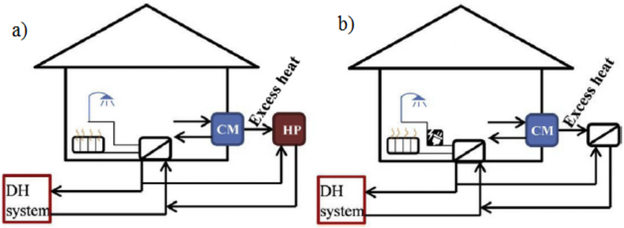

Fig. 6. Examples of waste heat integration into DH – a) with heat pump for higher temperature level and b) low temperature DH network [16]

Under the case a) in Fig. 6 it is assumed that the DH network and buildings need higher temperature and therefore a heat pump (HP) is necessary to increase the temperature of the prosumer heat to the required temperature level. In the case b) in Fig. 6, the excess heat is directly exported to the DH grid, while buildings may have possibility to increasing the temperature level, by including an electric boiler.

In [19] it is shown that with increasing number of prosumers, a transformation of today's DH network into smart grid is necessary. The introduction of prosumers to the DH will affect both the DH network and the customers. Introduction of prosumers will lead to lower DH temperature, because of: 1) lower temperature requirement for utilization of renewable and waste heat and 2) renewables produce heat with higher efficiency at lower temperature level. Heat production from the prosumers to the DH network will influence pressure levels in the DH network. When the prosumers produce at their maximum, the water velocity in the pipes will increase. Therefore, it is necessary to analyze pipe sizes before introducing prosumers and size the pipes for production instead of consumption. Further the prosumers may create own pressure cones resulting in high differential pressures for some of the consumers close to the prosumers. Opposite, the prosumers may decrease pressure difference when the supply water from the prosumer is mixed with the warmer water from the main plant. To enable higher heat share from the prosumers, it might be advantage to allow lower initial pressure difference from the main plant. However, this may result in the low pressure difference for the customers not affected by the water from the prosumers [19, 20]. Therefore, new control strategies for the differential pressures are highly important to enable proper operation of the whole DH system with the prosumers.

3.3. Successful examples of integration of excess heat

Nowadays datacentres need lots of cooling, while condensers of the cooling plants may provide heat for useful purpose. Integration of the excess heat may be done in the supply or in the return line of the DH system. Viborg DH in Denmark is an example where the surplus heat from the new Apple computer center is rejected to the DH system [21]. To provide heat for the DH system, high temperature heat pumps are implemented, thus providing directly supply water for the DH system of approximately 50°C. To enable this, Viborg DH had a long-term plan for decreasing the DH temperature and distribution losses, see Fig. 7. Customers with the high temperature requirements will be grouped and provided with an additional heat pump for increasing the temperature level.

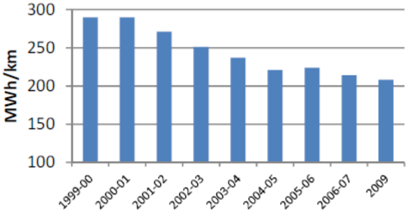

Fig. 7. Planned decrease in the DH distribution heat losses in Viborg DH to enable utilization of excess heat from the datacenter

In Trondheim, Norway, excess heat from cooling the datacenter at the university campus was utilized by connecting in the return line. The reason for this was currently high temperature level of the DH system in Trondheim. To enable integration of the excess heat, the university campus separated from the main connection to Trondheim DH by using heat exchangers and establishing own DH ring. In that way, it was possible to control the supply and return water temperature in the university DH ring and utilize excess heat from the datacenter. Currently, the excess heat may provide the base load in the range of 1 to 1.2 MW entire year.

4. Optimization, interaction, and energy measurement

To enable low supply temperature in the DH system, it is highly important to decrease as much as possible the return temperature. Importance of the low return is pointed out in Section 3 for the purpose of integration of the renewables and excess heat. An approximate calculation shows that the economic value of reduced return temperature can vary from 0.05 to 0.5 EUR/MWh°C [22]. A big problem in achieving low return temperature is poor substation control. Different faults induce problems with high return temperature in the consumer substations, see Fig. 8. Control and set points are causing most of the issues in achieving the low return temperature. Therefore, fault detection and diagnosis (FDD) of the consumer substations is highly important in achieving low return and consequently low supply temperature in the DH system.

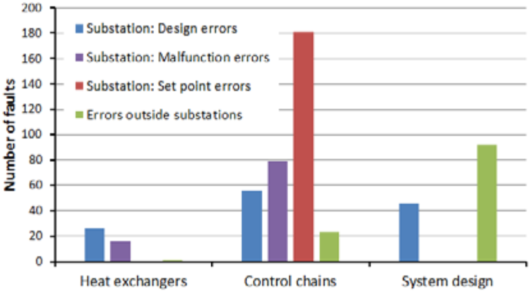

Fig. 8. Amount of fails in the consumer substations [22]

Wireless and smart metering technologies may provide lots of data on the substation performance and the DH network. By transforming these data into information, it is possible to improve the overall system operation and optimize the overall system performance considering together DH companies and consumers. Better data utilization may create new business development and build new business models tying utilities, energy companies, and consumers tighter together. New business models may be relevant for the DH companies and new actors on the market. For DH companies, this may imply that they can take over operation and maintenance of the consumer substations and operate them in the optimal way for the DH plant and costumers. In addition, new companies transforming data into useful information by using the newest IT-technologies and advanced control may be developed. An example for such company is NODA in Sweden. This company is dealing with big data applications for energy heating systems.

5. Price and business models

District heating pricing is a core element in reforming the heating market, because the heat price and price for the heat export will influence decision on energy source and an active customer role. Existing DH pricing methods, such as the cost-plus pricing method and the conventional marginal-cost pricing method, cannot simultaneously provide both high efficiency and sufficient investment cost return [23]. The cost-plus pricing method is often used in regulated DH markets. The marginal-cost pricing method is commonly utilized in deregulated markets [24].

Regarding excess and solar heat delivery to the DH system, several price and business models have been developed. In Denmark, DH operators are mostly organized in cooperatives. Their goal is not profit maximization, but to achieve a long-term favorable price using renewable energies for heating. An example of solar heating plant is in Marstal on island Aerö, Demark. The 33 400 m^2 solar collectors combined with the 75 000 m^3 storage provide 55% of the yearly heat demand. The district heating company is citizen-owned. In Gothenburg, Sweden, owners of the DH connected buildings installed large solar collectors. In this case, the solar heat is first used in the buildings. When the solar heat production exceeds the heat demand of the building, it is be exported to the main DH network. The DH network is kind of storage for the solar heat. In this example, where the building owners installed the solar collector, a problem with delivering less heat then expected has been noticed. In Austria, Energy Service Companies (ESCO) own and operate the solar heating system. This means that ESCO is the third party company [25].

Based on the available data on the solar heat production, it seems that the price and business models in Denmark resulted in a very high share of the solar heat into the DH system. In addition, the Danish DH solar systems are rather big plants than many small plants. In this model where the solar heat plant is owned by the DH company, proper operation is directly provided enabling desired temperature levels and operation conditions.

6. Conclusion

In the IEA DHC Annex TS1 project, the Subtask C collects and identifies promising models, concepts, and technologies to meet the goals of future renewable based community energy systems. The problem of the improved interfaces in DHC may be explained via hard and soft issues.

Energy planning of the future integrated energy systems is a complex problem. The analysis of the future heat demand showed that the DH would still be needed for most of the buildings in 2050, inducing that the LTDH would be a promising heat supply for the future. Considering that there is enough available heat from renewables and waste heat sources at the low temperature level, the LTDH will be highly needed in the future. For future development of the DH and a high reliability of the LTDH, statistical data and knowledge on the heat losses and how operation and temperature levels may contribute to the distribution losses are highly necessary. For example, only companies that have a long-term plan to include renewable energy sources have good databases and documentation on heat losses and temperature levels.

Integration of distributed energy systems will be realized by a new actor at the DH market called "prosumer". Increasing number of the prosumers will require a transformation of today's DH network into smart grid. Control strategies for the temperature levels and differential pressures in the network are highly important to enable successful connection of the prosumers into the DH system. Therefore, better data utilization may create new business models for both DH companies and IT sector.

References

[1] Nord, N. and S.F. Sjøthun, Success factors of energy efficiency measures in buildings in Norway. Energy and Buildings, 2014. 76: p. 476-487.

[2] On the Energy Performance of Buildings, Directive 2010/31/EU of the European Parliament and of the Council, E. Union, Editor 2010, Official Journal of the European Communities, Brussels.

[3] Kurnitski, J., et al., Cost optimal and nearly zero (nZEB) energy performance calculations for residential buildings with REHVA definition for nZEB national implementation. Energy and Buildings, 2011. 43(11): p. 3279-3288.

[4] Nielsen, S. and B. Möller, Excess heat production of future net zero energy buildings within district heating areas in Denmark. Energy, 2012. 48(1): p. 23-31.

[5] Li, D.H.W., L. Yang, and J.C. Lam, Zero energy buildings and sustainable development implications - A review. Energy, 2013. 54: p. 1-10.

[6] Marszal, A.J. and P. Heiselberg, Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark. Energy, 2011. 36(9): p. 5600-5609.

[7] Osmani, M. and A. O'Reilly, Feasibility of zero carbon homes in England by 2016: A house builder's perspective. Building and Environment, 2009. 44(9): p. 1917-1924.

[8] Guckenheimer, J. and J.M. Ottino, Foundations for Complex Systems Research in the Physical Sciences and Engineering 2008, Report from an NSF Workshop in September 2008.

[9] Andersen, K.K., H. Madsen, and L.H. Hansen, Modelling the heat dynamics of a building using stochastic differential equations. Energy and Buildings, 2000. 31(1): p. 13-24.

[10] Lü, X., et al., Modeling and forecasting energy consumption for heterogeneous buildings using a physical-statistical approach. Applied Energy, 2015. 144: p. 261-275.

[11] TheLowEnergyCommittee, Efficiency improvement, 2009, Norwegian Ministry of Petroleum and Energy.

[12] Persson, U. and S. Werner, Heat distribution and the future competitiveness of district heating. Applied Energy, 2011. 88(3): p. 568-576.

[13] Persson, U., B. Möller, and S. Werner, Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy, 2014. 74(C): p. 663-681.

[14] Kristjansson, H. and B. Bøhm, Pipe network models for system analysis, in The 11th International Symposium on District Heating and Cooling2008: Reykjavik, Iceland.

[15] Tereshchenko, T. and N. Nord, Importance of Increased Knowledge on Reliability of District Heating Pipes, in Cold Climate HVAC 20152015: Dalian.

[16] Brange, L., J. Englund, and P. Lauenburg, Prosumers in district heating networks - A Swedish case study. Applied Energy, 2016. 164: p. 492-500.

[17] Schleicher-Tappeser, R., How renewables will change electricity markets in the next five years. Energy Policy, 2012. 48: p. 64-75.

[18] Menniti, D., et al. Demand response program implementation in an energy district of domestic prosumers. in IEEE AFRICON Conference. 2013.

[19] Brand, L., et al., Smart district heating networks - A simulation study of prosumers' impact on technical parameters in distribution networks. Applied Energy, 2014. 129: p. 39-48.

[20] Lennermo, G., Substation and connection principles of the solar heat, Personal communication, 2016.

[21] Diget, T., The local potentials - Apple and other excess heat sources, in Viborg District Heat Conferance - Conferance on Excess Heat from Apple2015: Viborg, Denmark.

[22] Frederiksen, S. and S. Werner, District heating and cooling, 2013, Lund: Studentlitteratur.

[23] Zhang, J., B. Ge, and H. Xu, An equivalent marginal cost-pricing model for the district heating market. Energy Policy, 2013. 63: p. 1224-1232.

[24] Li, H., et al., A review of the pricing mechanisms for district heating systems. Renewable and Sustainable Energy Reviews, 2015. 42(0): p. 56-65.

[25] SDH Solar District Heating in Europe - Guideline for end-user feed-in of solar heat, J.-O. Dalenback, Editor 2015.