Technical University of Denmark

Low Temperature District Heating for Future Energy Systems

Subtask D: Case studies and demonstrations

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Low Temperature District Heating for Future Energy Systems

Subtask D: Case studies and demonstrations

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VTT Technical Research Center of Finland

Preface

This report titled "Case studies and demonstrations" is the subtask D report of the IEA DHC|CHP Annex TS1 project "Low Temperature District Heating for Future Energy Systems" carried out between 2013 and 2016. The project was led by Fraunhofer Institute for Building Physics (IBP) with the other participants being VTT Technical Research Centre of Finland (VTT), Technical University of Denmark (DTU), Norwegian University of Science and Technology (NTNU), Stuttgart Technology University of Applied Sciences (HFT) and SSE Enterprise in United Kingdom.

The demonstration cases described in the report include examples on low temperature district heating systems, solar heating in a district heating system, heat pump based heat supply and energy storages for both peak load management and for seasonal heat storage. Some demonstrations have been implemented while others are at planning phase. The implemented cases have provided measurement data for the verification of different calculation tools and analysis while the projects in planning phase have benefited on simulation results on operation of a realised system.

The collaboration group would like to thank the partners for the cooperation making the presentation of the case studies possible in this report.

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1 Introduction

This report is part of the project IEA DHC|CHP Annex TS1 project "Low temperature district heating for future energy systems" and describes the results of the Subtask D within the project called "Case studies and demonstrations".

The introduction chapter includes a overview of the project and describes the content of the report.

1.1 Overview of the project

The project consists of five subtasks with each reported both individually and within a summary report for the whole project. The subtasks, a general framework used within the project and relations between the subtasks are illustrated in Figure 1 below.

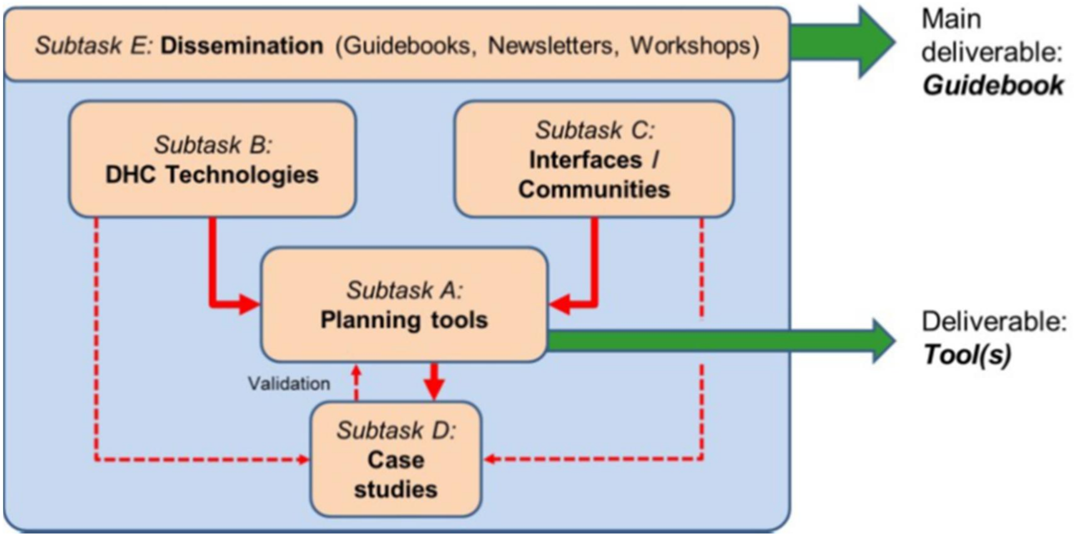

Figure 1. Structure of the project with expected output and connections between subtasks.

Objectives of *Subtask A* are the identification and adaptation of a methodology for assessing and analysing procedures for optimising local energy systems. The aim is to develop simplified and advanced tools for design and performance analysis of energy systems within communities based on district heating. Subtask provides the framework for more detailed analyses of district heating networks in combination with the different heat production facilities and with the heat supply on a community or neighbourhood level. Based on the conducted analyses, generalised guidelines on e.g. future design or retrofit of district heating and cooling systems can be derived.

Energy systems consist of a number of components and subsystems. These are identified and analysed within *Subtask B.* The focus here is on innovative solutions to meet the goals of a future renewable based energy supply for communities. At the component level, some specific topics are to be addressed, such as low temperature district heating substations, installation of domestic hot water preparation using low temperature heat supply, piping and transport concepts, heat generation facilities, such as advanced combined heat and power systems. Identification of promising technologies is done in context of future renewable based community energy systems. The projects take into consideration the framework derived from *Subtask A* and provide concepts for distribution, generation and storage of thermal energy that meet the demands of community members with a minimum input of primary energy.

The core issues in *Subtask C* are the identification of interfaces and dependencies between the different subsystems and actors along the energy chain from supply to consumption. The management of energy use, in particular, might offer new system layout and operational strategies. This may lead to innovative and more cost efficient designs and to a higher potential for integrating variable renewable energy. A closer look at economical boundaries of the projects and new possibilities for new business opportunities are part of the activities of this subtask. The subtask is focused on the interfaces between an advanced generation technologies, supply of thermal energy and the optimised demand management within the community. The holistic, systematic approach is used within the subtask to prevent the introduction sub-optimal systems.

The main topics in *Subtask D* are the identification, demonstration and collection of innovative community level energy concepts. Advanced technologies and the interaction between components within a system are demonstrated. Based on the evaluation of the collected examples of 4th generation district heating (4GDH), the tools developed in *Subtask A* and the implementation of combined dynamic analyses in *Subtask B* and *C* show the potential of the approach for district heating systems. Within this *Subtask D* already realised low temperature community energy system concepts as well as planned or designed systems are identified and presented. Based on the experiences, design guidelines are derived. Also, validation of the models and tools developed within *Subtask A* using measured data from these community projects is carried out.

Main work items in the project are:

- Application of advanced system concepts including solutions for the distribution, local generation and energy storage
- Use of innovative control concepts and strategies for a demand controlled supply
- Collection of realised community projects
- Validation procedure of community design and planning tools.

The results of *Subtasks A*, *B*, *C* and *D* are to be provided as input to the joint dissemination activity within *Subtask E.* All collected information and task specific results will be published. New target groups are to be identified and new means of spreading the information sought. The plan is to summarise the findings of Annex TS1 activities in a joint summary report in order to simplify public access and utilisation of the results.

1.2 Report content

The report describes eight demonstration activities in total within Europe, each reported within a single chapter. The case examples are from United Kingdom (UK), Germany, Finland, Denmark and Norway.

Each chapter includes a general overview of the studied system, technical description of the technologies used and the main results and outcome. In addition, many also include information of the related project and the involved stakeholders, measurement data monitoring and utilisation as well as methods used.

2 Low temperature energy efficient district heating in Slough

The Greenwatt Way scheme and Slough (United Kingdom) is a research project aiming to understand the actual consumption of heat and electricity usage within an energy efficient environment. The development comprises of a mixture of two and three bedroom family homes and one-bedroom flats. The houses, compliant with the Code 6 of the Code for Sustainable Homes[1] (CSH), are provided with heat from a range of renewable heat technologies via a mini District Heating (DH) system whilst integrated solar photovoltaics (PV) tiles on the roof provide renewable electricity. Figure 2 illustrates the included neighbourhood.

Figure 2. Visualisation of the included neighbourhood.

2.1 Technical description

The development consists of two 1-bedroom flats, a terrace of three 2-bedroom houses, a terrace of three 3-bedroom houses and two 3-bedroom detached houses with an overall heated area of 845 m2. Part of the area is illustrated in Figure 4.

Each home is fitted with one substation with direct connection for space heating and an instantaneous heat exchanger for DHW. Located in the living space of each home, one radiator supplies heat together with and a towel rail in the bathroom. Radiators are designed for temperatures of 55/35 °C. The homes also feature a Mechanical Ventilation Heat Recovery System (MVHR) that allows to reach the Heat Loss Parameter of 0.8 W/m2 K required by CSH. The heat recovery system is supplied by the radiator circuit and allows further cooling of return temperature. This setup with radiators connected in series with heat exchangers of the ventilation system was effective at bringing the district heating return temperature down.

[1]The Code for Sustainable Homes is the UK national standard for the sustainable design and construction of new homes. A star system (1 to 6 stars) is used to rate the performance of a new homes in terms of energy efficiency as well as choice of materials, water conservation and ecology.

Figure 3. View of the houses.

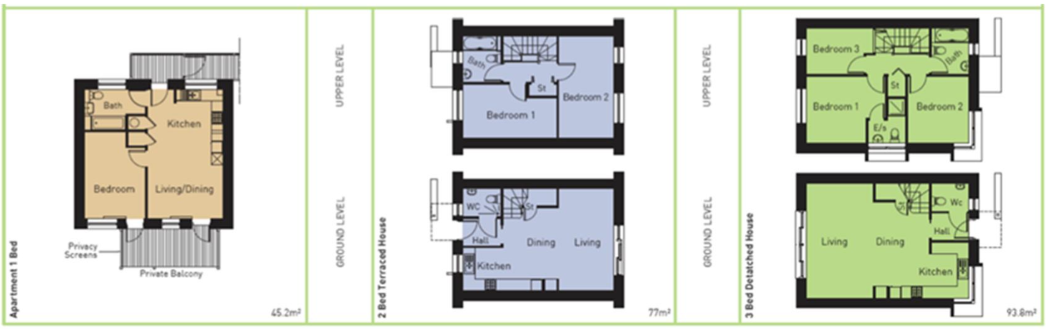

Figure 4. Floor plans of the dwellings.

The scheme is designed to operate at a constant temperature of 55 °C; domestic hot water is supplied at 43 °C via the instantaneous heat exchangers. The energy centre includes the following energy sources:

- 20 m^2 of solar thermal panels
- 2 x 17 kW ground source heat pump each with 7 boreholes
- 2 x 20 kW air source heat pump
- 30 kW biomass boiler
- 8000 l thermal storage

Each technology, solar thermal excluded, has been sized to meet the overall requirement of the site. The ground source heat pumps, the air source heat pumps and the biomass boiler can work independently and each of them is able to meet the full heating demand of the development.

The thermal storage allows the plant to run with greater flexibility and efficiency e.g by allowing the solar thermal to charge the storage when the solar irradiation is high. The stratifying thermal storage features multiple connections to allow staged heating by heat pumps i.e. water first heated up to 45 °C by the first heat pump cycle and then up to 55 °C by the second heat pump cycle. The mini district heating network is built with a mixture of Logstor steel pipes and Aluflex pre-insulated twin pipes. The main pipeline is 98 m long with diameters ranging from 50 mm to 32 mm. Connection pipes are 67 m in length with a diameter of 25 mm (twin steel pipes for flats and information centre) and 26 mm (twin Aluflex pipes for houses). The network layout is visualised in Figure 5.

Figure 5. Layout of the district heating network.

The annual heat consumption of the dwellings is 35.7 MWh. The heat supplied by the energy centre amounts to 49.6 MWh/year, indicating heat losses of 28%. The main indicators are compiled in Table 1 below.

Table 1. Summary table for the main indicators for Greenwatt Way system.

Overall length of the pipeline trench	165 m
Heat consumption	35.7 MWh/year
Heat delivered from energy centre	49.6 MWh/year
Average heat losses	28%
Linear heat density	0.319 MWh/m
Average temperatures[2] during the heating season	51.7/31.7 °C
Average temperatures outside the heating season	50.5/38.5 °C

2.2 Measurement data

For each substation there are two separate meters, one for space heating and the other for domestic hot water that collect and allow logging of data with a 5 min time resolution. Energy centre parameters are also logged at 5 min intervals. Below are the summary results from one year of monitoring showing demand for domestic hot water and space heating (Figure 6) and energy supplied to the network with relative heat losses (Figure 7).

[2] Supply and return temperatures.

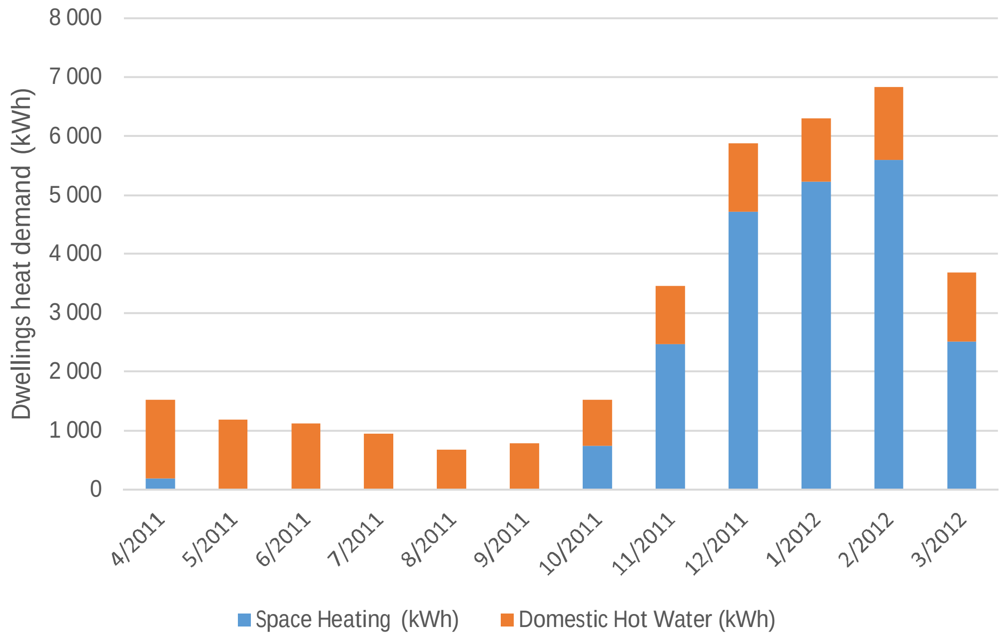

Figure 6. Space heating and domestic hot water demand as measured from April 2011 to March 2012.

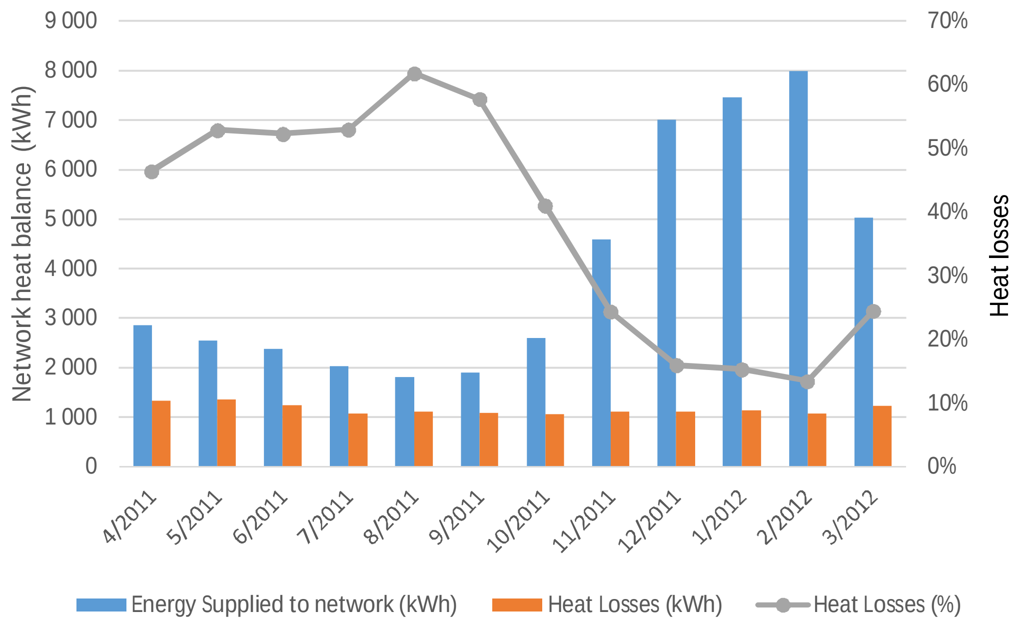

Figure 7. Energy supplied to the network and energy losses in distribution. In grey is indicated the relative weight of heat losses over the total energy supplied to the network.

2.3 Project and outcomes

The demonstration was implemented between December 2009 (constructed was started) and September 2010 (development occupied). The monitoring period was a year from 4/2011.

Main activities within the project were:

- Post Occupancy evaluation
- Modelling and monitoring of the energy performance of the energy centre, district heating and domestic heat and power demand
- Evaluation of the MVHR
- Monitoring of PV generation
- Monitoring of water usage
- Evaluation of hot fill washing machine and dishwasher

Lead organisation, the developer and the owner for the system was SSE the research partners being National House Building Council (NHBC), Building Research Establishment (BRE) and University of Reading. The total budget for the demo was £3.65 million. The demonstration system received support in the form of feed-in tariff for the large PV arrays on each house, but no support for the heating system itself.

The main deliverables for the project were:

- Evaluation of energy consumption in nearly zero carbon houses
- Evaluation of users interaction with nearly zero carbon house systems
- Demonstration of construction techniques deployed to build nearly zero carbon houses

3 Energy efficient district heating network in Ludwigsburg

The Renewable Energies Heat Act (EEWärmeG) states that the share of renewable energy in heat generation in Germany is to be increased to 14% by 2020. The expansion of district heating systems is seen as an important element in achieving this goal. District heating enables easy integration of renewable energy sources and results in higher efficiencies in energy conversion. The use of combined heat and power in heating grids is an additional option. However, existing district heating networks are often not optimised. Systems suffer from high heat losses, high return temperatures and high electrical consumption in pumping. Deviations between predicted and measured temperatures, pressures and mass flows are very common. Reasonable planning and operation of the systems can potentially increase their energy efficiency. The economics involved drive many heating system operators to be hesitant over combining renewable options with existing centralised heat production.

Decentralised heat supply for small or isolated areas or so-called micro-grids in many cases are preferable to an uneconomical expansion of existing district heating networks. In these systems, decentralised solar heating can help saving costs during summer periods when energy demands are very low (only DHW). So it may be more cost efficient to utilise decentralised heat supply than to operate centralised heat generation in partial load.

The main objectives of the project are to develop a simulation environment for efficient integration of decentralised renewable heat sources in existing or planned heating grids. Applicable results are to be implemented on a real heating network in the Sonnenberg district of Ludwigsburg.

Figure 8. Trenches being built in the Sonnenberg district of Ludwigsburg.

3.1 Technical description

Sonnenberg has a new district heating grid supplied by a gas CHP plant combined with a geothermal heat pump. Both are located in an old heating plant now refurbished and reopened. The municipal energy supplier, Stadtwerke Ludwigsburg-Kornwestheim GmbH, installed and will operate the planned new district heating. All purchase contracts for the Sonnenberg building sites include a clause making the connection to the district heating network compulsory.

The gas CHP unit has a capacity of 350 kWth and the geothermal heat pump a capacity of 200 kWth. The buildings are equipped with a substation and decentralised heat storage tanks, visualised in Figure 9.

Also, smart metering with a centralised control unit is installed in the buildings. The new distribution system's design includes an optional low exergy expansion with temperature levels (40/25 °C). The design temperatures of the main network are 70/40°C and thus, significantly higher.

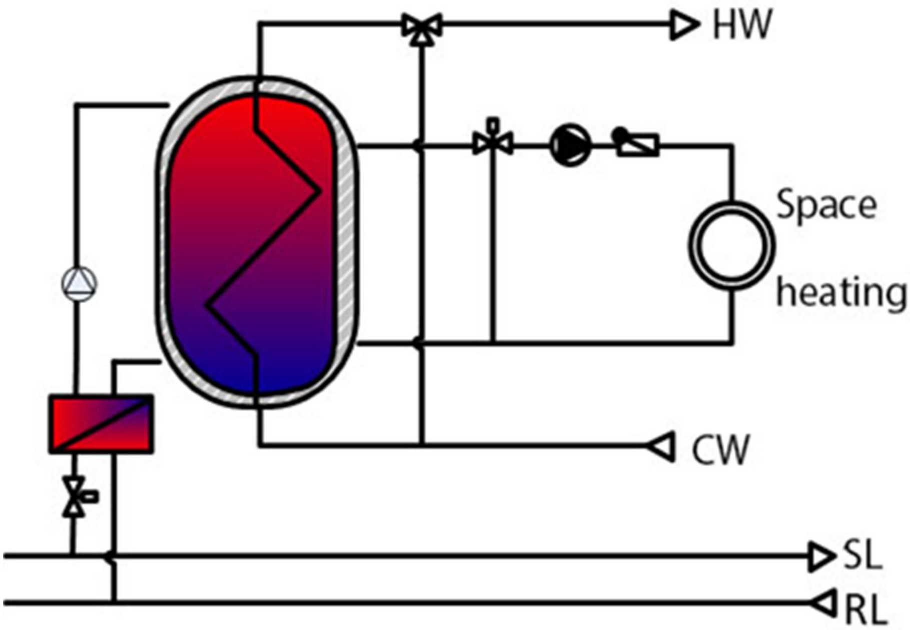

Figure 9. Substation connection in the Ludwigsburg system.

30% of the new Sonnenberg district, supplied by the LowEx subnet (blue area) is planned in to achieve the low energy or passive house standard. Thus, the planned grid extension can be operated by the return line of the existing grid. The layout of the distribution network is presented in Figure 10.

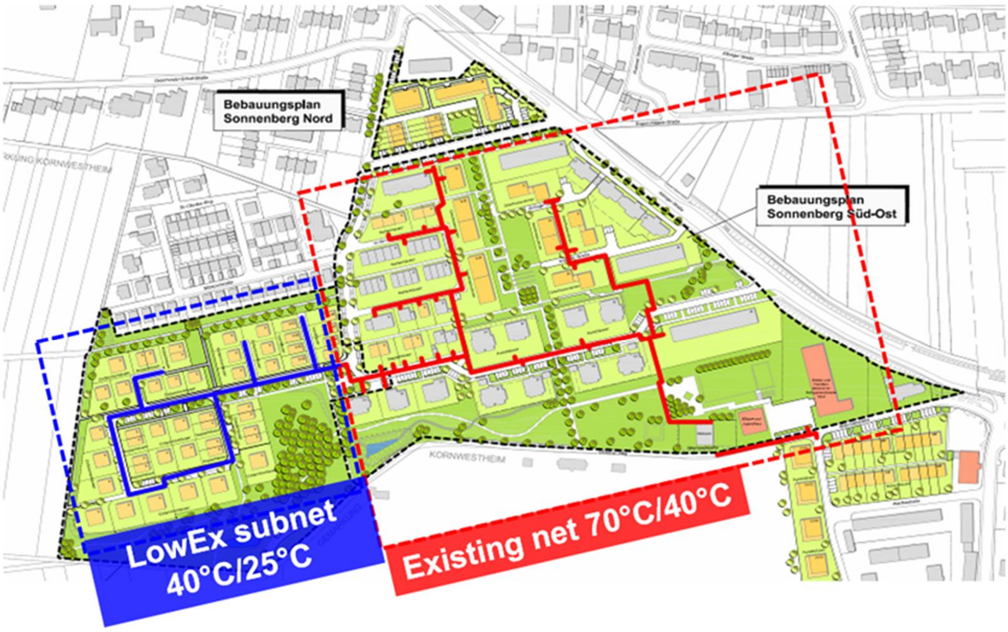

Figure 10. Overview of the existing and planned district heating network in Ludwigsburg.

The project focuses on heat demand evaluation by studying the operation of the grid. Special attention is paid to the management of heat supply and storage tanks' charging strategies. Detailed grid simulations help to optimise system operation.

3.2 Project and outcomes

Stuttgart University of Applied Sciences (HFT Stuttgart) acted as the project lead while the implementation was carried out by Stadtwerke Ludwigsburg-Kornwestheim GmbH, which also owns the system. The demonstration project was started in 1st January 2012 and was concluded on 31st August 2014.

The main results of the project are:

- Development of a substation for active consumers allowing bidirectional heat transfer to and from the district heating network
- Testing facilities for validation of numerical simulation models
- Simulation based optimisation of network control
- Creation and validation of an overall network model of city quarter Sonnenberg
    - Containing numerical models for heat generation units, distribution network and detailed consumer models

4 Residential area with geothermal heating & cooling in Wüstenrot

A strategy for making Wüstenrot (Germany) a plus energy community by 2020 was developed within the EnVisaGe project. This means that the community's yearly energy production would be more than the actual energy consumed within the community. As one important step towards that goal, a plus energy residential district with 24 mostly single-family houses was built.

To achieve the plus energy standard for all buildings, a high energy standard - almost passive house standard - was demanded by regulation. All buildings are equipped with large PV systems. The heating energy of the buildings is delivered by decentralised heat pumps. The heat pumps are connected to a central geothermal system. Thus, they can achieve a high coefficient of performance. This system consists of a cold water district heating network, delivering low temperature heat to the heat pumps. The novel agro-thermal collector is used as a low temperature heat source for the network. The concept of the system is to activate agricultural fields as geothermal collectors. This is done by deep ploughing the tubes 2 m below the ground surface, interspaced at a distance of 1m. The process is pictured in Figure 11 and Figure 12.

Figure 11. Technology for thermal activation of agricultural fields or other free spaces.

Figure 12. Thermal activation of the agricultural field in Wüstenrot.

The agro-thermal collectors can also be used for direct cooling of the buildings during summertime. This is in addition to using the cold water network (Figure 13) for heating during the winter period.

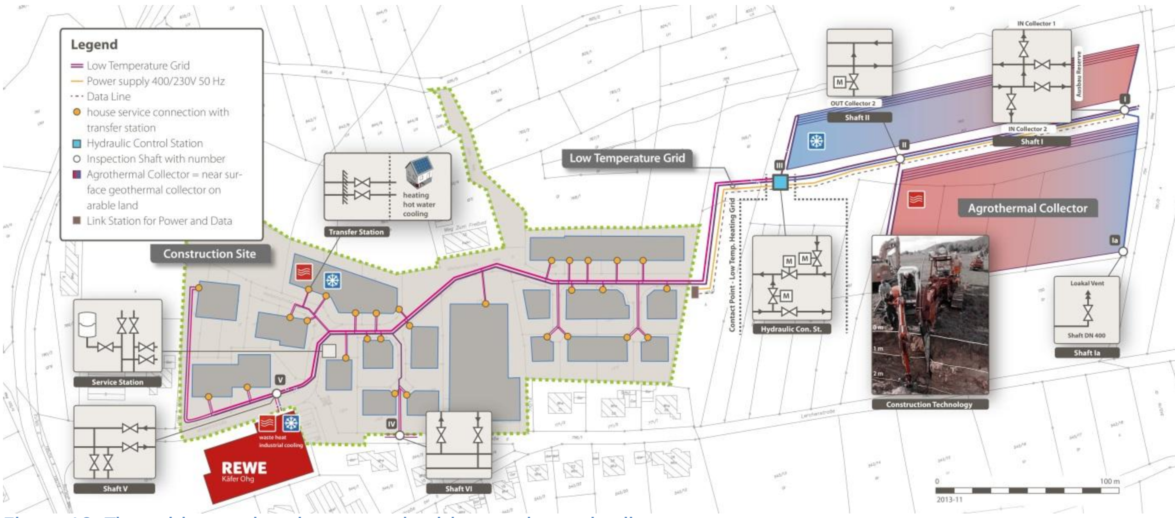

Figure 13. The cold water heating network with agro-thermal collector.

Furthermore, the system offers the possibility to combine heat sinks (heat pumps) and heat sources (e.g. re-cooling of compression chillers) for highly efficient energy use. In the demonstration system, this combined utilisation is being demonstrated and analysed by integrating the re-cooling of a supermarket cooling device (REWE Market). This supermarket is located near the plus energy district. A special technology for this is being developed by the company Doppelacker, which is based in Berlin, Germany.

The connections between the buildings and the local energy system are shown in Figure 13 and Figure 14.

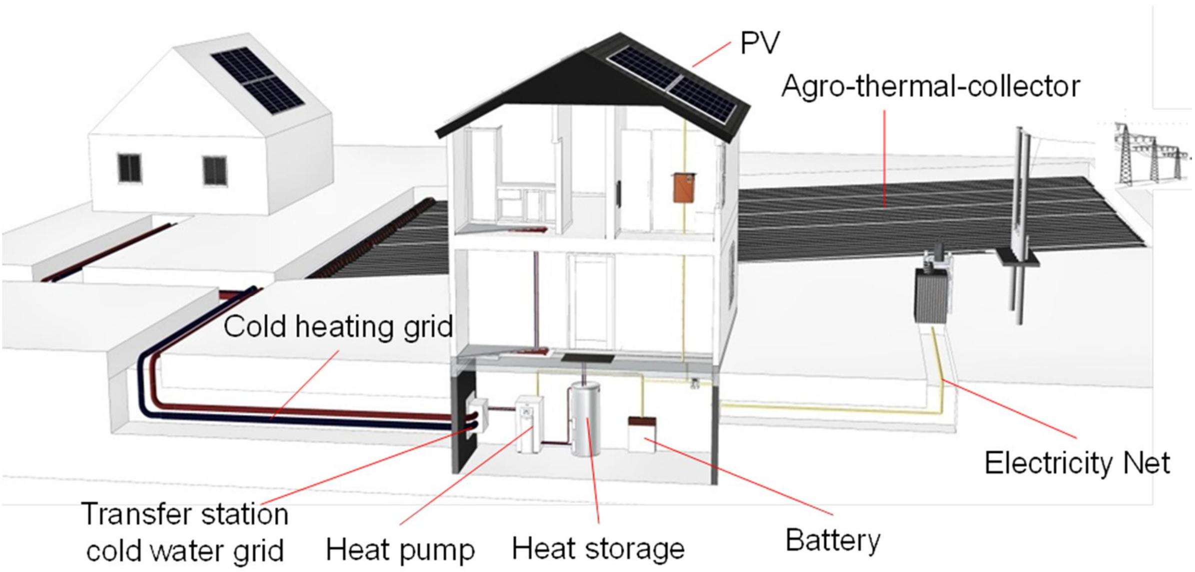

Figure 14. Connections between buildings and the energy system in Wüstenrot.

4.1 Measurement data

Monitoring was carried out first for a single building. More detailed monitoring systems were installed by the end of 2016 for 6-8 more buildings, as well as for the heat supply system. The monitoring results of the first building are presented in Figure 15 and Figure 16.

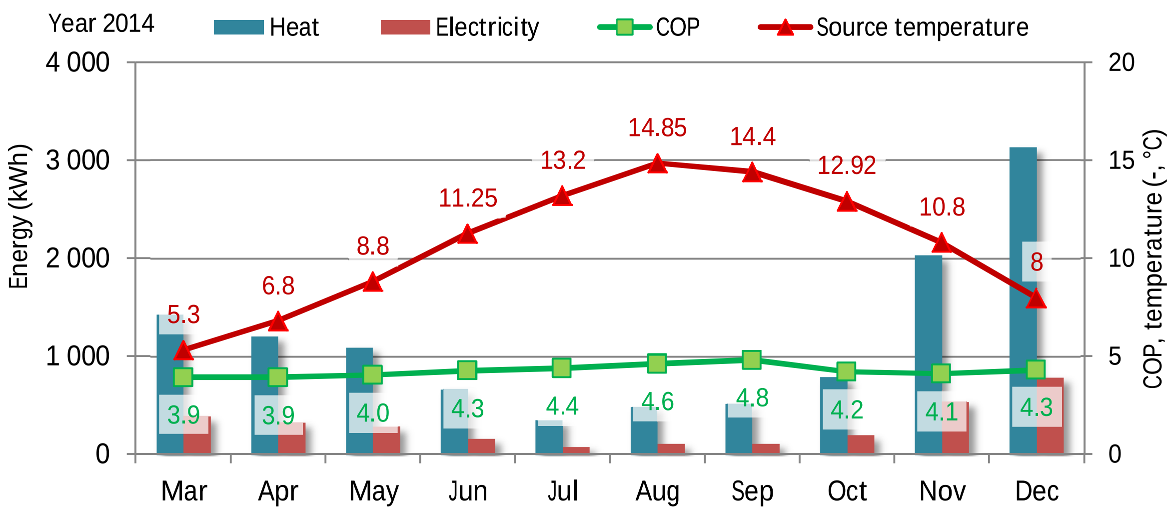

Figure 15. Measured performance data of one building in the plus energy district in 2014.

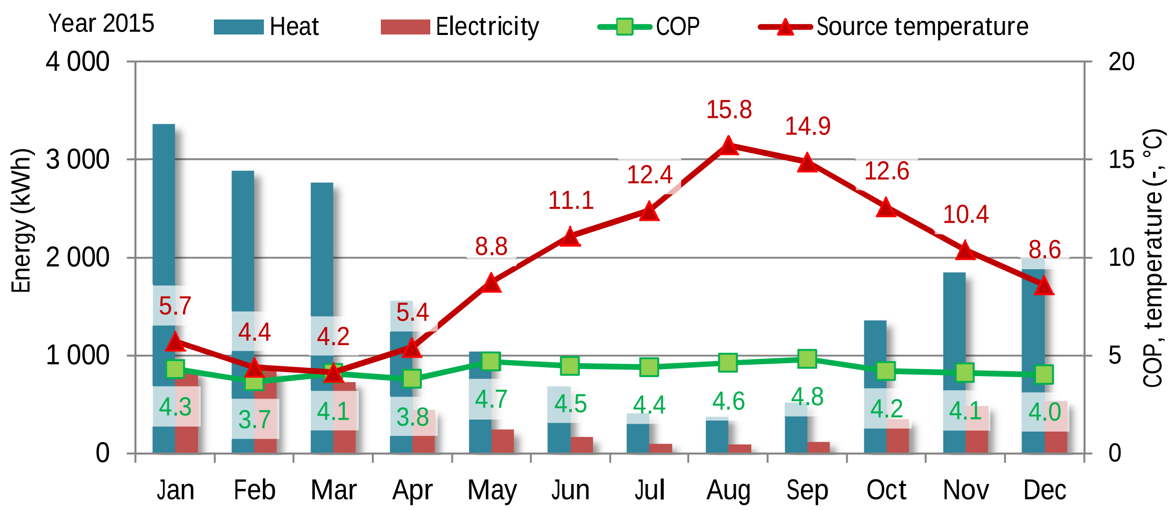

Figure 16. Measured performance data of one building in the plus energy district in 2015.

Measurement data collected from the more detailed monitoring system include:

- Low temperature heating/cooling energy delivered to the building
- Feed and return temperature of the cold water grid at the heat pump (evaporator side)
- Volume flow of the supply line of the cold water grid
- Pressure difference of supply and return line
- Total heating energy delivered by the heat pump (hot water and space heating)
- Supply and return temperature of the heat pump at heating circuit (condenser side)
- Volume flow heating circuit
- Heating energy delivered to domestic hot water preparation
- Power consumption of the heat pump
- Power consumption of the feeding pump (heat pump)
- Power consumption of the circulation pump/cooling operation

4.2 Project and outcomes

The coordinator and scientific partner in the project was Stuttgart University of Applied Sciences (HFT Stuttgart) and the participating organisations and their roles were:

- Municipality of Wüstenrot (demonstration partner)
- ads-tec GmbH (cloud based secure data transfer and storage)
- Liacon Batteries GmbH (Supplier of electricity storages for single family homes)
- die Erneuerbaren (project management for the municipality of Wüstenrot)
- Doppelacker GmbH (cold water network and agro-thermal collector technology developer)
- Vattenfall Europe Wärme AG (accounting methodologies, system operator and connection to virtual power plant)
- ZSW Stuttgart (intelligent load and storage management, electricity storage and PV)

The overall objectives of the project were to:

- Demonstrate the efficiency and economic viability of cold water heating/cooling grids with agro-thermal collectors
- Show the efficiency of the connected decentralised heat pumps and of direct cooling applications in the buildings
- Demonstrate the combined performance of the system with heat sinks (heat pumps) and heat sources connected (re-cooling of the super market cooling device)
- Development and testing of intelligent load and storage management to increase own-consumption of PV electricity
- Offer electricity sinks to the municipality's distribution grid by connecting the virtual power plant
- Development and implementation of an innovative and secure cloud based solution for data collection and transfer
- Development of an intelligent load management system

The objectives were met by following deliverables:

- System installation of the agro-thermal collector
- Connection of 16 buildings to the cold water heating grid
- Monitoring data of at least 6-8 buildings for one year (in progress)
- Monitoring data of the agro-thermal collector fields and cold heating grid (in progress)
- Simulation model for the agro-thermal collector (to be further validated during the monitoring phase)
- Development and implementation of an intelligent load and storage management.

The project duration is from July 2012 to June 2017. A project extension for monitoring is planned for a runtime of 3 more years, which will be followed by a long-term monitoring phase.

5 Future district heating solution for residential district in Hyvinkää

District heating has been an integral part of the Finnish energy system for decades. Its development started in 1950's and currently sits on a market share of 48 % within the heating sector. In the major cities, the market share is over 90 %. Finnish district heating systems are characterised by high efficiencies and high share of CHP based production (up to 75 %) in heat supply. In terms of distribution, the insulations standards used in Finnish district heating pipes are high compared to most other developed district heating countries.

The district heating system in Hyvinkää building fair area (Figure 17) is used a case study for low temperature district heating and for incorporating solar heating into buildings within a district heating area. Another point of view was to highlight the significance of planning by showing the effects lower than predicted connection rate. Currently, at the time of the study the connection rate within the area was 47 %. Other dwellings have chosen different heating solutions; boilers, collectors, heat pumps or a combination of these. Most of the buildings have underfloor heating for internal heat distribution, but some have radiators or ventilation based heating systems.

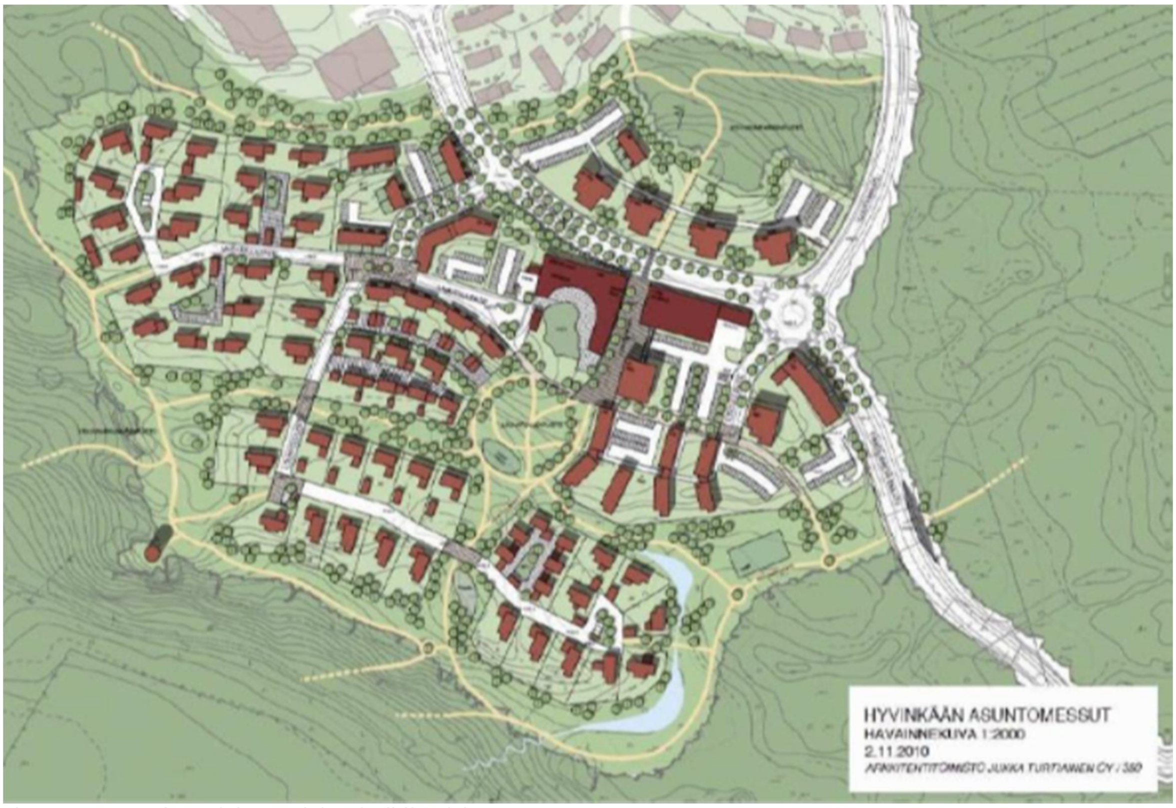

Figure 17. Overview of the Hyvinkää building fair area.

5.1 Technical description

The studied [3] area is part of the larger Hyvinkää district heating system. The connection to the main system is implemented using heat exchangers. As a result, the distribution temperatures in the area are lower than in the main system; constant supply temperatures of 85 °C and 75 °C are used during winter and summer time, respectively. As an additional simulation effort, the operation with a constant supply temperature of 65 °C was studied as well.

The distribution network in the area has a total length of 1 223 m or 1 675 m for 47 % and 100 % connection rate cases. It consists of pipes in sizes from DN40 to DN 200 with service pipes being either DN15 or DN32 depending on the consumer. The network structures for both the existing (47 % connection rate) and planned (100 %) system layout are presented in Figure 18.

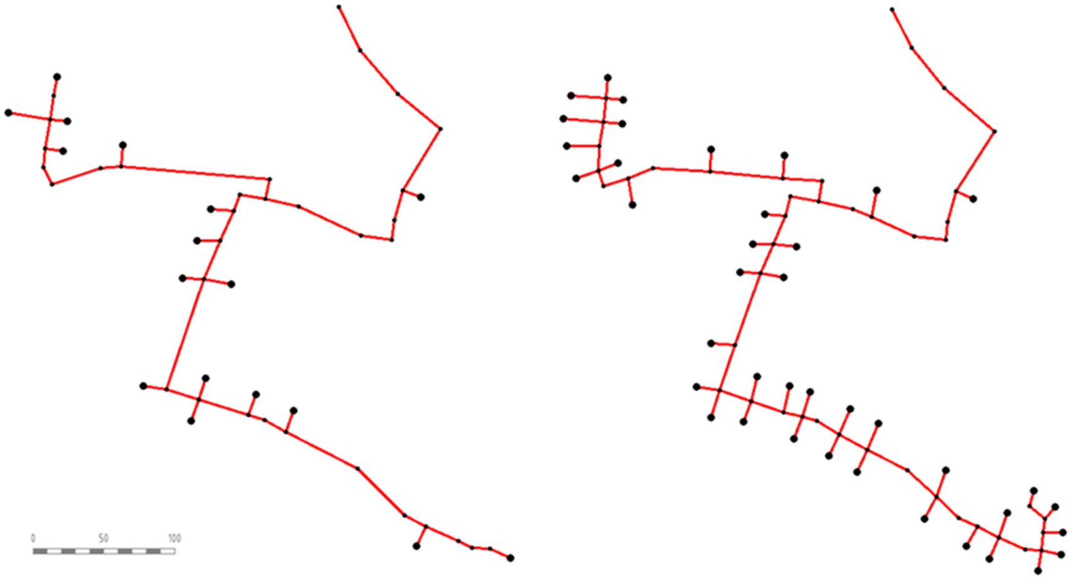

Figure 18. Network structure for 47 % connection rate (left) and 100 % connection rate systems.

Modelling of heat demand was carried out using IDA Indoor Climate and Energy simulation tool (space heating) and Apros Process Simulation Software (domestic hot water). The existing 47 % connection rate case had a heat demand (including heat losses) of 630 MWh and a linear heat density of 0.41 MWh/m (only consumption). The planned system (100 % connection rate) had 1 371 MWh of heat demand and a linear heat density of 0.74 MWh/m. Resulting combined year-long heat demand time series for planned, 100 % connection rate case is presented in Figure 19.

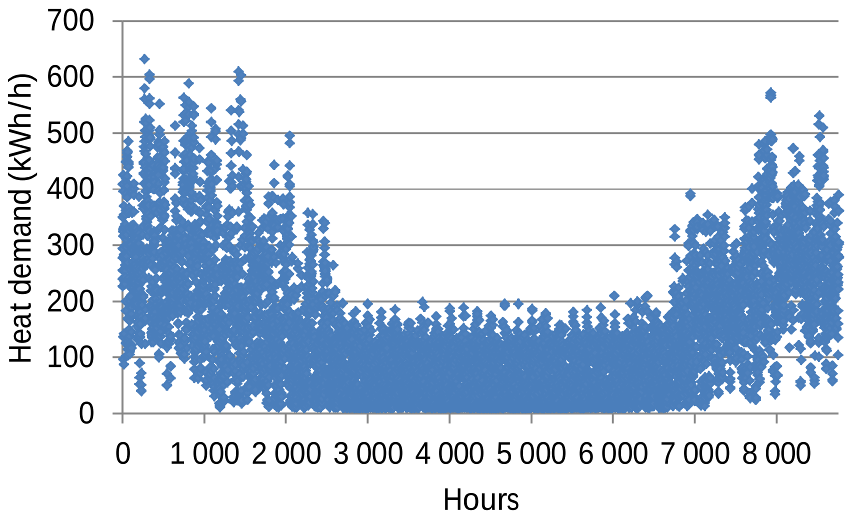

Figure 19. Hourly heat demand time series for 100 % connection rate case.

Monthly heat consumption for both existing and planned systems is visualised in Figure 20.

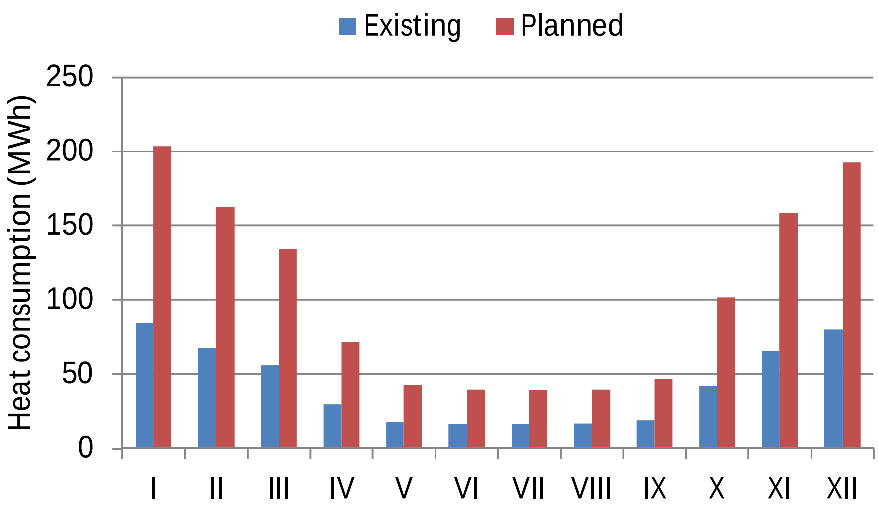

Figure 20. Monthly heat consumption for existing and planned systems.

In addition to the district heating system related analysis, an investigation of a solar collector system in a building connected to the district heating was carried out by series of separate simulations [4].

5.2 Simulation results

As the single most important indicator of the efficiency of the distribution system, relative heat losses were calculated based on simulation runs for each studied case. The results are presented in Figure 21.

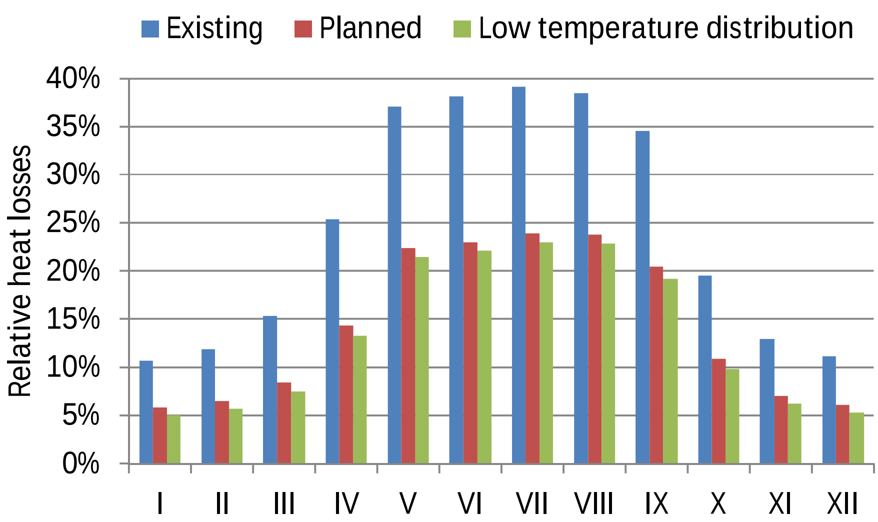

Figure 21. Monthly relative heat losses for the studied cases.

Results show the decisive importance of planning; heat losses in a system implemented as planned are almost as low as when utilising low temperature distribution. The differences between these two are less than they would be in a typical Finnish district heating system due to the already low temperature level maintained in the network within the studied area. Existing network is considerably less efficient.

For the 100 % connection rate case and adequate network structure, the annual heat losses were at a reasonable 10 % level. For the 47 % connection rate, heat losses were about 20 % of the heat energy supplied. Temperature variation and drop especially outside heating season was observed as a typical characteristic for a low heat demand district heating system. By-pass arrangements were used to alleviate this problem at the cost of increased heat losses, but connection pipes still experienced significant temperature drop.

In low temperature distribution case, the service pipes (DN15, DN40) were replaced by larger diameter pipes due to the increased flow rates. Otherwise, pipe dimensions within the network remained the same although the pressure drop in the network was considerably higher.

Other interesting results are the return temperatures from the area, presented in Figure 22.

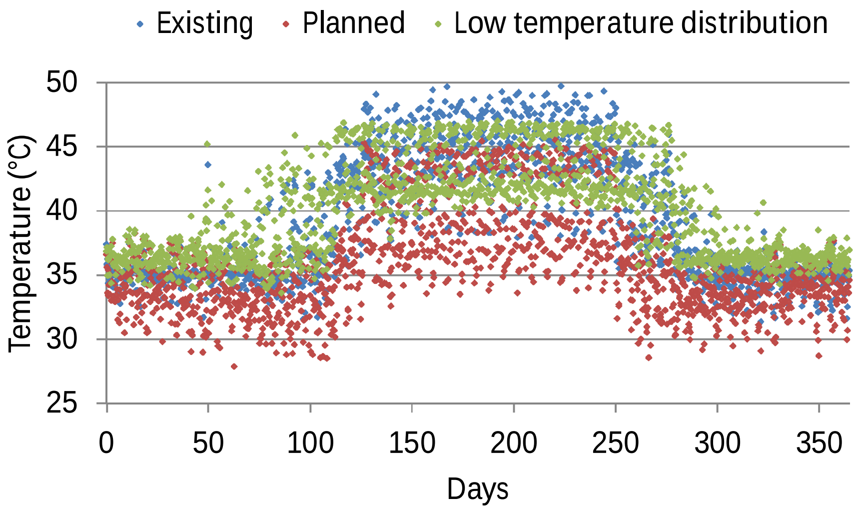

Figure 22. Return temperatures from the area for the studied cases.

The results how lowest return temperatures for the planned system and generally highest for the existing system. Low temperature distribution option still uses similar heat exchanger design and thus the higher flow rates cause higher return temperatures.

Different district heating connection options enabling solar heating together with district heating for both space heating and domestic hot water were analysed. A schema of one possible solar and district heating hybrid connection is presented in Figure 23.

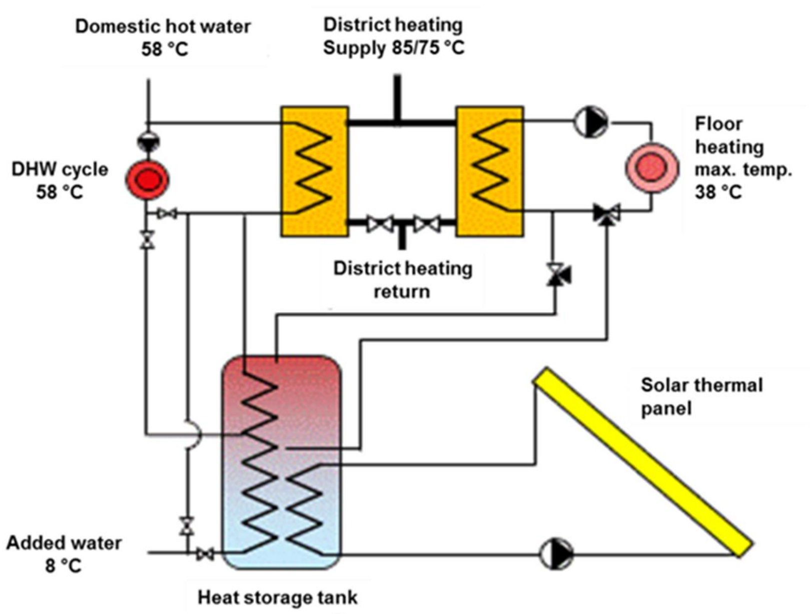

Figure 23. Hybrid heating connection combining solar and district heating.

Results of simulations show that the majority of the solar energy is taken from the storage for domestic hot water consumption, covering about half of its annual heat demand. Amount of solar energy used for space heating is small as there is not much collector output during the heating season. The results (Figure 24) correspond to a hybrid district heating and solar collector system for a detached house with 6 m^2 solar collectors, 400 l heat storage and an annual heat demand of 11.4 MWh for a 150 m^2 heated area.

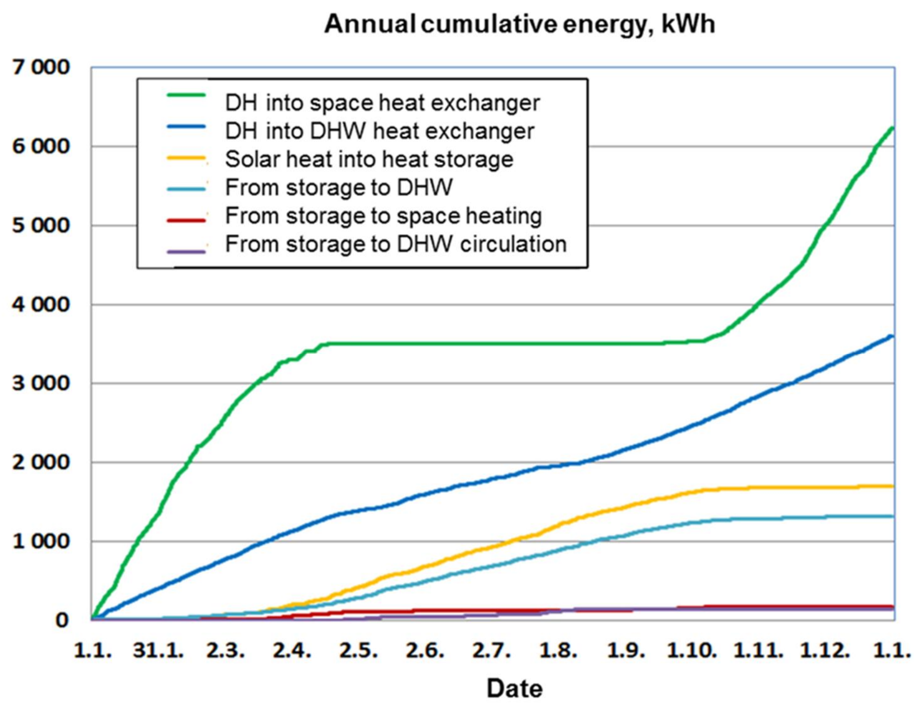

Figure 24. Cumulative energies in heat supply and consumption.

In parallel with the simulation work, life cycle costs (LCC) analysis was carried out. According to results, the district heating solution in a single family passive house, complying with the 2020's energy efficiency requirements, is a little more competitive compared to the solution using ground heat pump. Life cycle assessment (LCA) showed that the carbon footprint of a small district heated house can be reduced by building more energy-efficient house than current standards require. Additionally, approx. 50 % of greenhouse gas emissions can be avoided during the life cycle of 25 years, by increasing the share of renewable fuels in the district heat production. Utilisation of heating and electricity generated from municipal waste will reduce the building's carbon footprint.

5.3 Project and outcomes

The study was part of a larger project called "Future district heating solutions for residential districts" with following objectives:

- To develop adequate district heating solutions for residential low energy districts
- To compare alternative solutions by life-cycle assessment (cost and emissions)
- To evaluate the potential of utilising municipal and construction waste for district heating energy generation
- To investigate how nearly zero-energy buildings (in terms of the Energy Performance of Buildings Directive) affect the dynamics of local DH- network

The lead organisation of the project was utility Hyvinkään Lämpövoima (owner of the district heating network) and the other participating and funding organisations were Finnish Funding Agency for Technology and Innovation, City of Hyvinkää and Finnish Energy as well as energy utilities Ekokem Ltd, Jyväskylän Energia, Helsingin Energia, Porvoon Energia and Riihimäen Kaukolämpö. VTT Technical Research Centre of Finland was responsible for the research carried out in the project. Demonstration site was owned by the Hyvinkään Lämpövoima.

The project started in 10/2011 and was concluded in 12/2013.

References

[1] Krzysztof Klobut, Antti Knuuti, Sirje Vares, Jorma Heikkinen, Miika Rämä, Ari Laitinen, Hannele Ahvenniemi, Ha Hoang, Jari Shemeikka & Kari Sipilä. 2014. Future district heating solutions for residential districts. VTT Technology Report 187. 85 p + app. 11 p. (written in Finnish). http://issuu.com/vttfinland/docs/t187/0

[2] Kari Sipilä & all., 2015, Distributed Energy Systems (DESY), Technology Report 224, VTT, 186 p + app. 2 p. http://www.vtt.fi/inf/pdf/technology/2015/T224.pdf

[3] Miika Rämä, Jorma Heikkinen, Krzysztof Klobut, Ari Laitinen. 2014. Network simulation of low heat demand density residential area. The 14th International Symposium on District Heating and Cooling. Stockholm, Sweden. 4 p.

[4] Jorma Heikkinen, Miika Rämä, Krzysztof Klobut, Ari Laitinen. 2014. Solar Thermal Integration into a District Heated Small House. The 14th International Symposium on District Heating and Cooling. Stockholm, Sweden. 4 p.

6 Low-temperature district heating in Sønderby

The project is a full scale demonstration in Sønderby, Taastrup, in Denmark (Figure 7.1). The heated area includes 75 single family houses built from 1997-1998 with under floor heating systems. The demonstration aims to show that low temperature district heating (LTDH) works in existing buildings and identify solutions to minimise the high heat losses.

In the project, the old district heating (DH) system was replaced with new DH pipes and consumer substations. Through renovation, the temperature in the network is reduced from average 80°C to average 55°C. The demonstration project shows that there is a great energy saving potential by providing LTDH for existing buildings with underfloor heating as space heating system.

Figure 25. Full scale demonstration of low-temperature district heating, Sønderby, Denmark.

6.1 Technical description

The demonstration area includes 75 single family houses built from 1997-98 with living space ranging from 110 to 212 m^2, typically 2-5 people in each house. The houses have floor heating in all rooms which make it possible for LTDH supply. The heating degree day is 2 977.

The annual heat consumption in the buildings is in the range of 5 to 23 MWh / year per house (not include heat loss in the grid). Average consumption is about 13 MWh (based on consumption during the heating seasons 2004/2005 - 2009/2010). The houses originally had hot water tanks for domestic hot water (DHW) supply (110 L or 150 L). Before the project, the network supply temperature varied between 65-107 ^{o}C, with the lowest supply temperature in summer. The average supply temperature is 80 ^{o}C. The annual grid heat losses accounted for 38-44 % (average ≈ 41%) of the heat supplied from the central heat exchanger.

Through the project, high efficient twin DH pipes are installed to replace old very inefficient plastic DH pipes. Branch pipes are AluFlex flexible pipe with insulation class series 3. The larger pipes are insulation class series 2. The area is supplied from adjacent medium temperature DH network. Low temperature is achieved with a mixing shunt and a booster pump. All 75 houses are replaced with new instantaneous heat exchangers. The heat exchanger is specially designed for the low temperature difference and the high flow on the primary side, which is obtained by low-temperature operation with a flow temperature down to 50 ° C. All 75 houses are equipped with remote reading of power meters (Kamstrup MULTICAL® 601 with top module). The supply temperature to the low temperature network has averaged 55 ° C. The return temperature has annually been about 40 ° C, resulting in an overall cooling of about 15 ° C.

The main design parameters are:

- Network maximum level of pressure: 10 bar
- Maximum velocity in pipes: 2.0 m / s
- Peak load design outdoor temperature -12 ° C
- Thermostatic bypass set point 50^{o}C
- Heat loss coefficient (U value) based on the supply/return temperature 55/25 ° C and ground temperature 8 ° C.
- Minimum differential pressure: 0.3 bar
- Taastrup DH plant supply pressure 3.4 bar
- Taastrup DH plant return pressure 2.6 bar

Comparing with old DH system, the new DH system has the following features:

1. Low network supply/return temperature
2. Energy efficient and smaller dimension DH pipes
3. Mixing shunt and booster pump for low-temperature supply
4. New low-temperature instantaneous heat exchanger

These features result network heat loss reducing from 41% to 13-14%.

The low-temperature is supplied with a mixing shunt which regulates the temperature for the low-temperature network. The primary heat source comes from the return line of the medium temperature DH network. When the temperature in the return line is not sufficient, water from supply line of the medium temperature DH network will mix with return water to achieve the desired supply temperature. The system therefore consists of three pipes: two supply pipes and one return pipe.

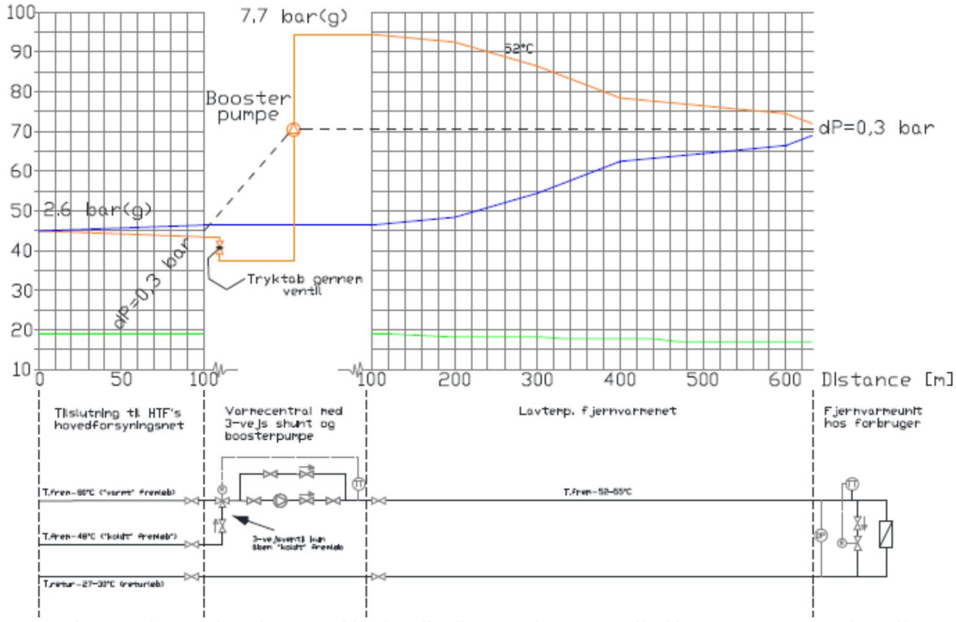

Figure 26. Diagram for mixing shunt and hydraulic diagram (area supplied by return water of medium temperature DH).

The 75 houses installed new low temperature instantaneous heat exchanger substations which uses Danfoss Redan Alva Lux II VX. The dimensioning temperatures at 32.3 kW is 52 / 18.6 ° C - 10/45 ° C, which corresponds to a primary flow of about 830 l / h. The heating circuit is directly connected with a differential pressure controller mounted over the heating circuit (Figure 27).

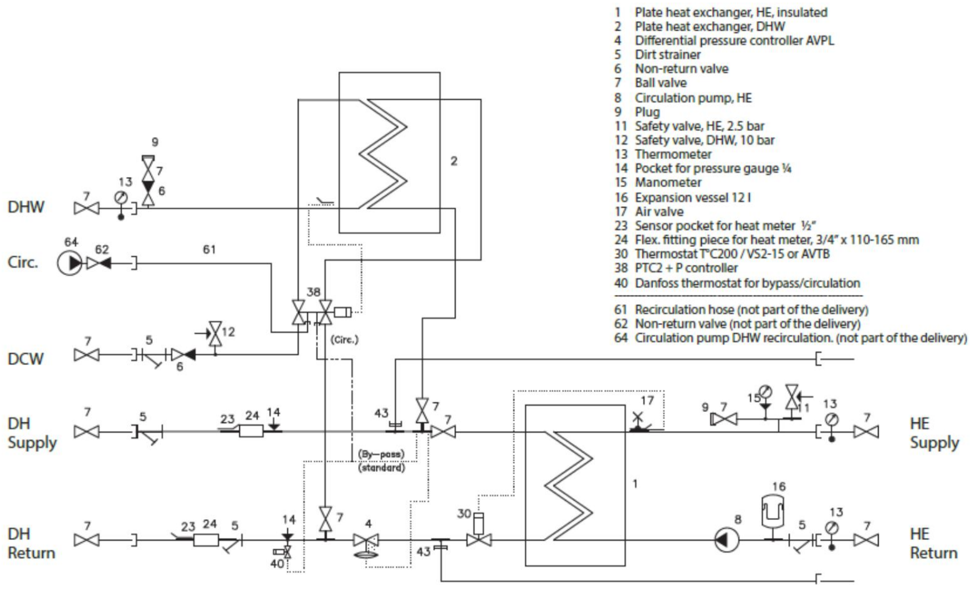

Figure 27. 3 Principle of flow exchanger water heater (Danfoss Redan Akva Lux II VX)

6.2 Measurement data

There made detailed measurements of operation of the new DH system in the period 1.1. 2012 - 1.7. 2013. The supply temperature to the low temperature network has averaged 55 ° C. The return temperature has annually been about 40 ° C, resulting in an overall cooling of about 15 ° C. All 75 houses are equipped with remote reading of power meters (Kamstrup MULTICAL® 601). The meters are used for billing of heat consumption in each house. These energy meters measure total consumption for both heating and hot water incl. heat loss from installations on the consumer side of the meter.

From each energy meter, hourly values of the following parameters are collected:

- Accumulated volume V [m^3]
- Accumulated energy [MWh]
- Thermal power P[kW]
- Supply temperature T1 [°C]
- Return temperature T2 [°C]
- Flow rate Q [l/h]
- Temperature difference, T1-T2 [°C]
- Thermal power P [kW]

At the heating plant, two pieces energy meters (Kamstrup MULTICAL® 601) were used. The following data are collected in 5-min values:

- Medium DH network supply temperature T1[° C]
- Medium DH network return temperature T2[° C]
- Mixed LTDH supply temperature T3[° C]
- Medium DH network return flow rate V1 [m^3/h]
- Medium DH network total flow rate V2 [m^3/h]
- Supply absolute pressure Ps [bar (g)]
- Return absolute pressure Pr [bar (g)]
- Differential pressure at critical user [bar]
- Heat delivered to LTDH network [MW]
- Electricity consumed for booster pump [kWh]

6.3 Main activities and results

In the full scale demonstration project, the old inefficient DH pipes were replaced with better insulated AluFlex pipes and the old water storage tank substations were replaced with low-temperature instantaneous heat exchanger substations. The heated area is supplied through a mixing shunt and a booster pump. In the project, detailed measurements and data collection were performed. These measurement data are processed and analysed for the period 1 January 2012 to 1 July 2013.

The demonstration project showed that it is feasible to supply LTDH to existing area with floor heating as space heating. The results show that it is possible to supply DH consumers with a flow temperature of 50 - 53 ° C, which is sufficient to cover the space heating demand, and to permit the production of domestic hot water in a secure manner. Comparing with old medium temperature DH system which has average grid heat loss approximately 41 %, the new system reduces the heat loss down to 13 – 14 %. The energy efficient goal in the project has been met. The reduction in heat loss is a result of lower temperature in the DH network, and then heating pipes with better insulation properties.

The full-scale demonstration project included a new supply concept. The low-temperature network is supplied with return water from the medium temperature network from the neighbouring Taastrup DH. This supply temperature is averaged at 48 ° C and the supplied energy covers about 80% of the total supply. Its remaining supply is covered with warmer water from the supply line from the neighbouring network. The advantage of the concept is that the supply capacity of an existing district heating network can be increased without requiring any further investment costs. Moreover, it provides a lower return temperature in the overall DH network, which reduces the heat loss and can provide higher efficiency in heat generation plant. The supply concept requires that there is an adjacent area with a sufficient flow in the return line and a relatively high return temperature.

In the project, it was found that the average network supply temperature is 55 °C and return temperature is around 40°C, which results an overall cooling of about 15 °C. The less cooling is deemed to have given a greater need for pumping energy, but this is still a small percentage compared to the total savings in losses in networks. There are several explanations for the higher return temperature, but the main reason is just too great a bypass flow in some user installations caused by defective or incorrectly set control valves. It is also considered that many consumers do not close for "summer valve" in their water heater. The problem with that consumers do not get closed summer valve may in future projects may be handled with electronic supplemented with a return temperature limiter on space heating heat exchangers.

Project lead was by COWI A/S and other participating organisations Danfoss A/S, Logstor A/S and Kamstrup A/S. The owner of the demonstration site was Tastrup District Heating.

References

EUDP 2010-II, Full-scale demonstration of low temperature district heating in existing settlements (Fuldskalademonstration af lavtemperatur-fjernvarme I eksisterende bebyggelser). Journal Nr: 64010-0479

7 Geo-solar local heat supply for residential area in Kassel

The case system area "Zum Feldlager" is located in Kassel in the center of Germany. Currently the area is undeveloped land on which a new housing development is planned. Preliminary plan for the area is illustrated in Figure 28 and Error! Reference source not found.. The area is surrounded by existing buildings and there is a water protection area nearby. The new housing estate “Zum Feldlager” is located in an urban ventilation path. For that reason combustion of oil or wood (with possible fine particles) should be avoided. Due to the location of the area a connection to the existing district heating network of Kassel is not feasible because of logistical and economic reasons. As a result, a local district concept is implemented. The concept involves the use of renewable energy sources (RES) such as geothermal and solar energy for low temperature district heating and domestic hot water supply.

Figure 28. Preliminary urban planning concept for the new housing estate ”Zum Feldlager” [1].

The new housing estate will be characterized by a very compact construction and south oriented buildings; 1-2 storey detached and semi-detached houses in the north, two-storey terraced houses in the centre and large three-storey apartment buildings in the south. All buildings have specific heat demand of 45 kWh/m²a and a specific domestic hot water (DHW) demand of 730 kWh/person, a. Thus, the demand is significantly below the maximum energy demand for new buildings (<50 kWh/m²a for heating) according to the current valid German energy saving ordinance EnEV 2014. Numerical information concerning the area is collected into Table 2.

Table 2. Assumptions for the buildings and climatic boundary conditions according to the first planning.

Total number of buildings	127
Single-family houses (SFH)	46
Semi-detached houses (SDH)	32
Terraced houses (TH)	37
Multi-family houses (MFH)	12
Dwelling units	154
Persons per dwelling unit	4
Climatic conditions	2010
Orientation of buildings	south
Roof shape	SFH, SDH and TH = gable roof, MFH = flat roof
Transmission System	surface heating

7.1 Technical description

The system consists of a centralized heat pump powered by borehole heat exchangers (BHE) installed in a geothermal probe field. Depending on the supply variant, the soil acts as source in winter or as thermal storage in summer time. For the regeneration of the soil unglazed solar collectors (swimming pool absorbers as the low-cost option) are intended. The district heating grid is fed by the centralized heat pump. It is conceivable to use the district heating during heating period for provide (low temperature) heat.

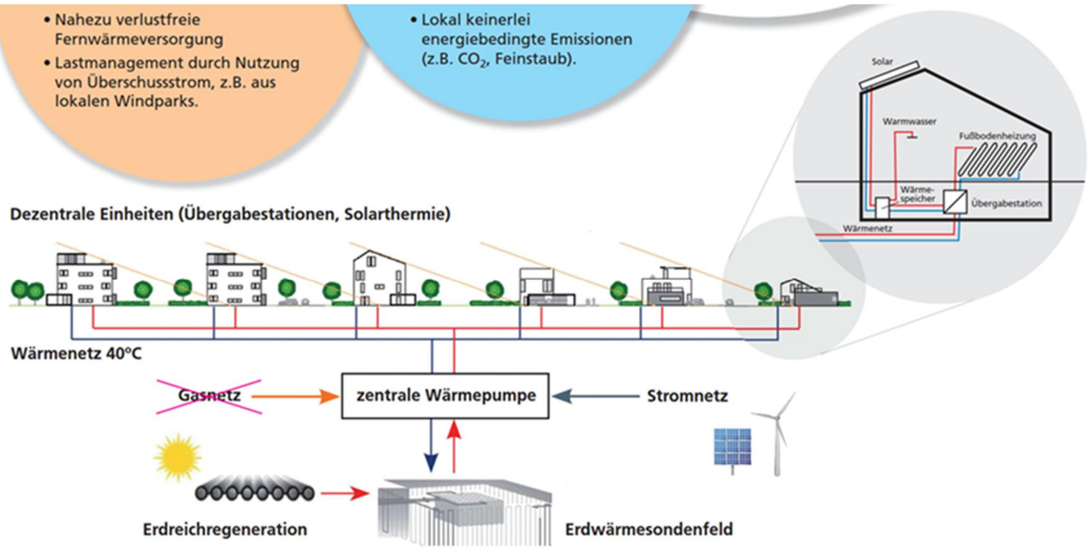

Figure 29. Arrangement and schema of the solar-ground storage systems.

The centralised ground coupled heat pump feeds the district grid at a temperature level of 40°C. The heat for space heating is supplied directly by the district heating network through the use of heat exchangers. For preparation of domestic hot water different variants are possible and foreseen. In case of separated domestic hot water preparation thermal solar panels (e.g. flat-plate collectors) or an electric heating element could be used. The solar panels could be installed on the roof or on carports. Another variant for domestic hot water preparation is usage the heat of the district heating grid, also in combination of solar panels and heating elements. The required temperatures lift is significantly lower.

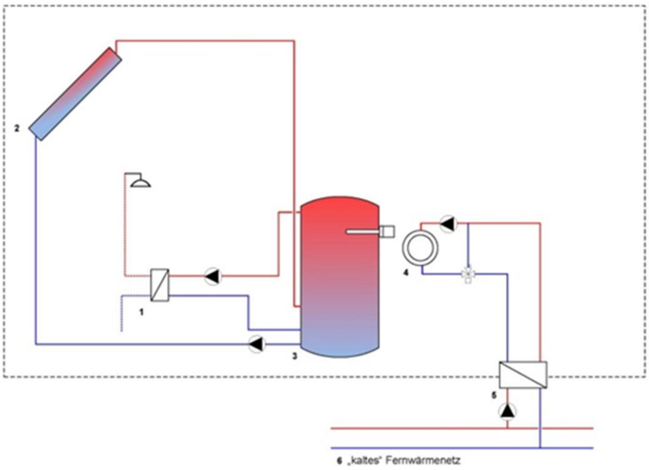

Figure 30. Heating system in the house and connection to the local district heating.

The advantages of this supply variant are slightly higher heat losses. Furthermore space heat could be directly used from grid (substation required). No decentralized heat pumps must be installed and thus the investments costs are lower.

7.2 Project organisation

The research effort in the project was carried out by the Fraunhofer Institute for Building Physics and University of Kassel (Department of Geotechnical Engineering & Department of Solar and System Engineering). The owner of the demonstration system was City of Kassel and the operator was the utility company Städtische Werke AG in Kassel. German District Heating Working Group (AGFW) was also involved in the project. The project started in 11/2015 and is to be concluded in 8/2017. The total investment costs were 3.7 M€ (demonstration) and 1 M€ (research, measurements).

The main activities for the project were:

- Soil reconnaissance
- Development of thermal simulation model of entire housing estate
- Development of industrial management and control strategies of district heating system (winter and summer case)
- Dimensioning of components
- Measurement and evaluation concept

References

[1] Plat no. IV/65 „Zum Feldlager“; Architektur+Städtebau Bankert, Linker & Hupfeld, city of Kassel- urban planning, building inspection and conservation; updated: 2nd February 2013.

8 Sea water heat recovery and heat pumps in Ulstein

In Ulstein (Norway), "Fjord" district heating is based on utilisation recovered heat from the sea and decentralized heat pumps. The recovered heat in low temperature is distributed to substations. Both heating and cooling is distributed using the same pipe network without any insulation. Low water temperature results in low heat losses and low operation cost. The local energy substation can be used for one or few buildings. The solution is suitable for locations on the coast. In Ulstein project, the sea water temperature was measured to be from 4 °C to 9 °C during the year at the depth of 42 m. In total about 15 energy substations will be connected to the system.

Figure 31. Pipelines for supplying water used as a heat source for heat pumps in a district heating system in Ulstein. (Photo, Øyvind Amdam, Ulstein municipality)

In the beginning, 20 % of the costumers are included in the district heating system. After five years, the connection rate will be up to 60 % and after 10 years 100 % of the capacity will be utilized. Additional capacity of 20 % as reserve is assumed to be utilized within 20 years. The total heat supply delivered by the district heating system will be higher than 10 MW within five years. Including the reserve capacity the plant should deliver about 20 GWh heating and 5 GWh cooling. It was assumed that the heating and cooling price will be about 0.7 NOK/kWh (1 NOK = 0.113 EUR).

The total investment within the first 10 years will be about 75 million NOK and 85 million NOK within 20 years.

9 Lower temperatures for existing systems in Middelfart

The district heating company in the Danish city Middelfart has been supplying heat to their consumers since 1963. During the past 7 years, the company has been working hard to lower the temperatures in the district heating network, that now delivers heat to approximately 5000 customers. This has resulted in a case project where supply and return temperatures have been lowered from an average of 80.6 °C / 47.6 °C in 2009 to an average of 64.6 °C / 40.0 °C in 2015. The district heating company has taken part in the development and test of software tools that can help in reducing the return temperature in district heating networks. Furthermore the company has demonstrated a process that district heating companies can follow when working towards a low-temperature operation profile. During the process the network heat losses in Middelfart have been lowered by almost 25 % and the economic benefits where estimated to approximately 5.5 million DKK/year (0.7 million €/year). Thereby the case project demonstrates that it is possible to obtain large energy savings by optimizing the district heating temperatures in existing networks.

Middelfart district heating supplies heat through two district heating networks, one in the city of Middelfart and one in the smaller nearby village Nørre Aaby. In Middelfart the district heating network consists of approximately 139 km of pipe and supplies heat to approximately 5000 customers. Customers cover a large range of different buildings but consist mainly of small customers such as single-family houses and few larger customers such as schools. The building mass in the city ranges from old buildings to modern low-energy buildings. Middelfart district heating is a distribution company, which means that they do not produce the heat, but buy it from a local heat supplier. The heat mainly consists of surplus heat from an oil refinery, CHP production, and heat from a waste incineration plant. The annual heat consumption in the city is approximately 480000 GJ per year. Key numbers for Middelfart district heating are seen below and the heating network in Middelfart is illustrated in Figure 32.

Figure 32. Illustration of the district heating network in Middelfart [Illustration from Middelfart District Heating].

9.1 Software tools used

Part of the process of lowering the district heating temperatures in an existing district heating network is to install software that can help optimize the district heating operation. In Denmark it is common to install software for real-time optimisation of district heating operation that is called Termis. Termis can be used to perform a Flow Temperature Optimisation (FTO), meaning that the program can use real-time data to lower the supply temperature in the network as far as possible without compromising the hydraulic capacity of the network or the customer requirements. However in order to move further towards low-temperature district heating, it is important also to lower the return temperatures. Therefore part of this case project aimed to develop a tool that can be used by district heating companies for Return Temperature Optimisation (RTO).

The development consisted of two steps. The first step was to develop software to collect information about the return temperature from all customer installations. The second step was to extent the Termis software to include customer information, and use it for return temperature optimisation. Most of the district heating meters installed in the substations of Danish district heating customers are remotely read, thereby allowing the district heating companies to easily collect metering data for billing purposes. These meters provide an opportunity to collect data from customers on a regular basis, and use this to monitor and improve the district heating operation. This made it possible to operate the district heating network as a smart grid, where the operation was optimized in real-time in Termis, depending on the customer consumption. Furthermore, the measurements from customer substations could be visualized and used to monitor the efficiency of customer installations, identify customer installations with high return temperatures, and plan efforts to reduce return temperatures from specific consumers.

9.2 Practical experiences and novelty value

Apart from development of software solutions, the project also aimed to collect experiences on the practical work with Return Temperature Optimisation. The developed software was installed amongst others at Middelfart district heating and the district heating company planned a process to lower the district heating temperatures. This process required a new vision of the services provided by the district heating company and a large amount of customer communication. Whereas the district heating systems are commonly considered to cover only heat production and distribution, Middelfart district heating expanded their service to include customer installations inside the buildings, as the operation of the district heating substations were continuously monitored by the district heating company. The district heating company was provided with an overview of customers that need to make a long term effort to lower a high return temperature, or customers that experience a malfunction in their installation leading to a sudden increase in the return temperature. If a substation is seen to provide a high return temperature, the district heating company offers a service check and provides advice for the customers on how to improve their heating installation. This is both a benefit to the customers, who receive additional service from the heating company, and for the company, as the return temperatures are continuously lowered in the network, when old inefficient installations are replaced. The service was provided by an employee that continuously monitors the operation of the district heating network on the basis of the new tools for data collection and Return Temperature Optimisation. Figure 33 shows an example of the measurement data from a customer where the substation was replaced in January as it was found to be old and not work properly.

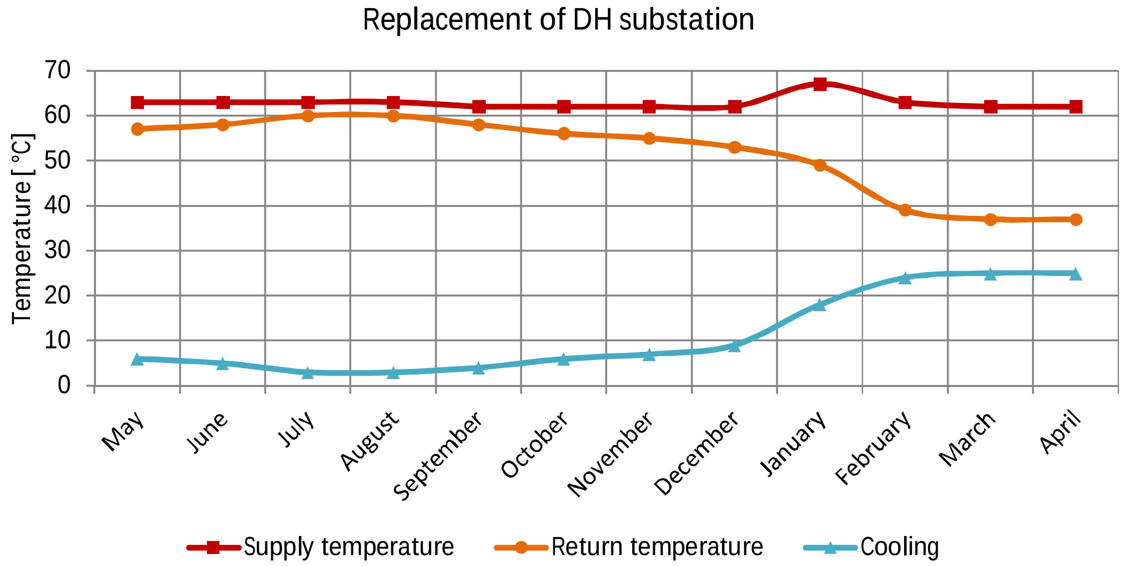

Figure 33. Example of monitoring a customer whose district heating substation was replaced.

When the return temperature is lowered, the price of the district heating becomes more favourable as heat losses are lowered, and production efficiency is increased. In order to motivate the customers to improve their heating installations and provide a more fair distribution of the actual heat price on each consumer, the district heating company introduced a return temperature tariff in their pricing structure. This tariff provides customers with a low return temperature with a financial bonus while customers with a high return temperature pay an extra cost according to the costs imposed on the district heating company due to higher heat losses and lower heat production efficiency. The district heating company made a large effort to advertise the new service provided and inform about the new return temperature tariff that was implemented. The experiences from the project therefore include successful implementation of a new district heating strategy where customer substations are included in the service area of the district heating companies and customers pay, not only for their heating consumption, but also for the actual cost they impose on the heating system.

Temperature optimisation provides a large number of benefits for the district heating company. First of all the heat loss from the pipe network is reduced when network temperatures are reduced. Reduction in return temperature furthermore ensures more energy efficient heat production from heating plants with flue gas condensation or heating plants based on for example solar heating. Additional benefits include the fact that when the return temperature is lowered, the same amount of heat can be delivered at a smaller mass flow rate. Therefore pumping energy can be reduced and network capacity increased. This can be very beneficial in district heating systems where the capacity limit has been reached, or where expansions are planned in the near future. The benefits can be summarised as:

- Lower heat loss from pipes
- More efficient heat production
- Lower power consumption for pumping
- Increased capacity in the district heating network

9.3 Measurement data

The demonstration project focused on collection of data from customer substations through a smart metering system. The metering data includes the following values measured at each of the approximately 5000 customer substations in the district heating network in Middelfart:

- Supply and return temperatures
- Energy consumption
- Water volume

The measurements are available to the district heating company at all times and can be visualized online or in the Termis software.

The overall heat consumption and heat losses in the network are monitored in order to evaluate the savings obtained by return temperature optimisation in the demonstration project. Figure 10.3 shows the network supply and return temperatures at the beginning of the project in 2009, and later in 2015[3]. Both supply and return temperatures have been reduced drastically during the demonstration project, through Flow Temperature Optimisation and Return Temperature Optimisation respectively. Key values for the operation of the district heating in 2009 and 2015 are given in Table 10.1.

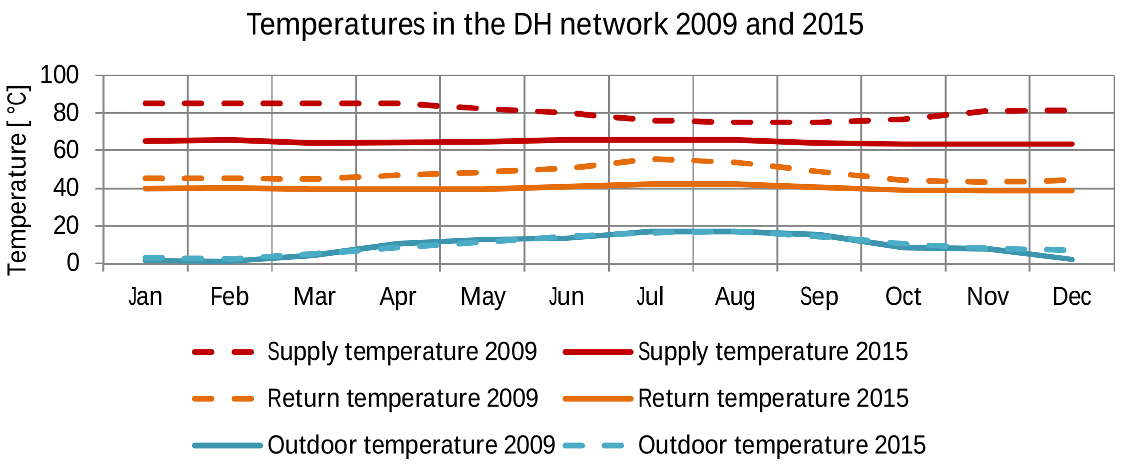

Figure 34. Average supply, return and outdoor temperatures during the years 2009 and 2015 [Measurement data from Middelfart district heating].

[3] The number of degree days in 2009 and 2015 were approximately 2800 and 2600 respectively. This difference should be kept in mind when comparing the data, but it is not significant for the temperature reduction.

Table 3. Key values for operation of the district heating system in Middelfart in 2009 and 2015.

	2009							2015						
	Tsup	Tret	Tout	Heat supply	Heat sold	Heat loss	Pump. energy	Tsup	Tret	Tout	Heat supply	Heat sold	Heat loss	Energy pump
	°C	°C	°C	MWh	MWh	MWh	MWh	°C	°C	°C	MWh	MWh	MWh	MWh
Jan	85.0	45.3	1.3	-	-	-	93	65.0	40.0	3.1	16 749	14 673	2 076	111
Feb	85.0	45.1	1.0	-	-	-	85	65.7	40.1	2.2	15 831	13 859	1 973	104
Mar	85.0	44.9	4.2	-	-	-	74	64.1	39.6	5.2	14 136	12 116	2 020	85
Apr	85.0	46.7	10.3	-	-	-	33	64.4	39.6	8.3	10 050	8 215	1 835	49
May	82.2	48.6	12.6	-	-	-	29	64.9	39.5	11.2	7 858	6 005	1 853	43
Jun	80.1	50.4	13.2	-	-	-	27	65.6	40.7	14.4	5 429	3 800	1 629	32
Jul	76.0	55.5	16.8	-	-	-	28	65.6	42.1	16.3	4 061	2 477	1 583	23
Aug	75.0	53.9	16.8	-	-	-	28	65.8	42.3	16.9	3 676	2 143	1 533	22
Sep	75.0	48.9	15.2	-	-	-	30	64.1	40.5	14.2	5 235	3 714	1 520	42
Oct	76.8	44.3	8.4	-	-	-	55	63.5	38.8	10.2	9 338	7 488	1 850	44
Nov	80.9	43.3	7.7	-	-	-	87	63.5	38.6	7.8	11 738	9 994	1 745	64
Dec	81.3	44.3	2.0	-	-	-	98	63.5	38.6	6.9	13 855	12 123	1 733	77
Total	80.6	47.6	9.1	125 716	97 527	28 189	667	64.6	40.0	9.7	117 957	96 201	21 756	696

As seen from

Table 3, the annual average supply and return temperatures went from 80.6 °C / 47.6 °C in 2009 to 64.6 °C / 40.0 °C in 2015. Due to the reduction in supply and return temperatures, the heat losses were reduced from 28189 MWh/a in 2009 to 21756 MWh/a in 2015, which meant that the heat loss was reduced by almost 25%. The difference between supply and return temperatures in the network was decreased during the project period, thereby causing the electricity consumption for pumping to increase. The electricity consumption for pumping increased from 667 MWh/a in 2009 to 696 MWh/a in 2015. This is an increase of 4% or approximately 100 GJ, which is a relatively small amount of energy compared to the savings on heat loss.

The economic savings obtained from the temperature reduction consist of savings due to lower heat loss and savings from a return temperature tariff that is paid to the local heat supplier. The savings have been estimated to be in the size of 110000 DKK/year per °C (14650 €/year per °C) due to heat loss reduction and 380000 DKK/year per °C (50650 €/year per °C) due to the tariff to the heat supplier. The average annual supply and return temperatures have been reduced by approximately 16.0 °C and 7.6 °C respectively. Based on the estimated savings, the temperature reductions provide a total saving of approximately 5.5 million DKK/year (0.7 million €/year).

9.4 Project results

The demonstration project has successfully shown how temperature optimisation can be implemented in existing district heating systems, and that it can lead to large energy efficiency improvements. The project demonstrates the possibility of including customer installations in the optimisation of the district heating system, by monitoring the operation of customer substations, providing service checks for customer installations, and implementing a return temperature tariff that motivates consumers to improve heating system installations. Ultimately the project provides software and process tools that can help existing district heating companies to lower the temperatures in the networks.

The main results of the project were:

- Development of system for collection and use of smart meter data from district heating substations
- Development of extension for the real-time district heating operation software Termis, to include a module for return temperature optimisation
- Demonstration of the use of smart district heating meters and software for return temperature optimisation in existing district heating systems
- Practical experiences from the process of optimizing return temperatures in district heating networks

9.5 Project organisation

Project lead responsibility was on COWI A/S and Middelfart District Heating had the ownership of the demonstration. Solution developers were Schneider Electric Denmark A/S (Termis) and MeterWare. Other participating organisation was Fjernvarmens Udviklingscenter.

9.6 Budget and schedule

Part of the demonstration has been carried out through a research and development project in 2013-2014. In this project, the software for smart metering and return temperature optimisation was developed, and tested by the district heating company. The budget of this project is seen below, as given on the project webpage [1]. More information about the research project can be found in [2] and [3].

Budget for research and development project on return temperature optimisation:

- Total budget: 6.90 million DKK / 0.92 million €
- Financial support: 2.14 million DKK / 0.28 million €

The budget was divided into the following parts in table 10.1.

Table 4. Budget of Middelfart project.

Company	Main deliverable	Budget
COWI A/S	Project coordinator, development of return temperature optimisation (RTO) in Termis software	2.32 million DKK / 0.31 million €
Skanderborg District Heating	Implementation of RTO software and collection of experiences from RTO process	0.84 million DKK / 0.11 million €
Middelfart District Heating	Implementation of RTO software and collection of experiences from RTO process	1.08 million DKK / 0.14 million €
Schneider electric Denmark A/S	Development of RTO in Termis software	2.09 million DKK / 0.28 million €
MeterWare	Development of smart meter solution	0.59 million DKK / 0.08 million €

The project was started in 2009 and temperature optimisation is continuously carried out. Part of the demonstration was carried out through a research and development project in 6/2013 – 12/2014.

References

[1] http://energiforskning.dk/en/projects/detail?program=7&teknologi=All&field_bevillingsaar_value=&start=&slut=&field_status_value=done&keyword=district%20heating&page=7

[2] T.A. Østergaard, Rto – Return Temperature Optimisation – By Use of Smart Meters and Hydraulic Calculations, in: 14th Int. Symp. Dist. Heat. Cool., 2014: pp. 7–10.

[3] COWI, Energieffektivering ved optimering af returtemperatur i fjernvarmesystemer [Energy efficiency improvements through optimisation of return temperature in district heating systems] - EUDP 13-I; Journal nr: 64013-0120, 2015.

10 Summary and conclusions

Core objective in Subtask D was top identify and collect innovative demonstration concepts as examples of success stories for communities interested in developing low temperature district heating systems. Demonstrated cases include use of advanced technologies and interaction between different components within the systems. Based on these experiences, principles and lessons learned in designing these systems are given. Measurement data from community projects are also used in validation of the models and tools developed.

There were a total of eight case studies from Germany, Denmark, Finland, Norway and Great Britain. The district heating systems were of very different sizes, from miniature to city wide systems. Network lengths were from 165 m to 140 000 m. The connected buildings were detached, terraced and block houses, and mostly low energy or passive houses. Sources of heat were solar collectors, heat pumps, CHP plants, excess heat from industry or the systems were connected to a larger network close by with heat exchangers. The temperature levels recorded were typical for low-temperature systems, varying from 40 to 60 °C in supply and 25 to 40 °C in return. Savings and increased efficiencies were observed in every case studied. The Table 5 summarises the case systems by listing yearly heat demands and distribution temperatures as well as giving a short description of each concept studied.

Table 5. Summary of the case study systems.

Case system	Heat demand	Temperatures	Short description
Slough (UK)	49.6 MWh/year	52/32 °C	Miniature district heating system with 10 dwellings and solar collectors, ground and air source heat pumps, biomass boiler and a heat storage as heat supply options.
Ludwigsburg (Germany)	825 MWh/year	40/25 °C	Storage and heat supply capability in consumer substations, two-way connection to a local low temperature district heating system. CHP unit and ground source heat pumps as the centralised heat supply options.
Wustenrot (Germany)	376 MWh/year	40/30 °C	Decentralised heat pumps for each consumer, utilising heat from collector pipes buried in agricultural fields. All dwellings are passive houses with PV systems on roof-tops. Cold water network can also be used for cooling and rejection of excess heat.
Kassel (Germany)	1827 MWh/year	40/30 °C	Low temperature district heating system for 127 buildings with heat supply consisting of solar collectors, a centralised ground heat pump with boreholes that can be utilised also as seasonal heat storage. Use of electric heating elements or solar collectors for DHW production is studied.
Hyvinkää (Finland)	630/1 371 MWh/year	65/35 °C	Building fair area with local district heating system consisting of 40 consumers. Solutions for combining distributed solar collector systems and district heating, the effect of connection rate and low distribution temperatures are studied.
Sønderby (Denmark)	975 MWh/year	55/40 °C	Complete renovation of pipe system for a part of a larger district heating system. Reduced distribution tempeartures and return flow in the core network used as the main heat supply. Heat losses reduced approximately by 66 %.
Ulstein (Norway)	20 000 MWh/year	4-9 °C	Cold district heating system using sea water as the heat source for decentralised heat pumps at the consumer buildings. Can also be utilised as free cooling.

Middelfart (Denmark)	118 000 MWh/year	64.6/40 °C	Demonstration of process for lowering the supply and return temperatures systematically across a large scale system of 5000 consumers and 139 km of pipes. Issues with individual consumers mostly corrected by normal service operations. In addition to lower supply temperatures, the return temperatures could be lowered as well, reducing the effect of normally increased flow rates. Tools developed for dynamic simulation of temperature levels within the network.

Greenwatt Way (UK) has a system of 10 dwellings with 845 m^2 heated floor area, supplied by a miniature district heating system with a trench length of 165 m. Heat supply consist of 20 m^2 solar thermal collectors, two 17 kW ground source heat pumps with 14 boreholes, two 20 kW air source heat pumps and a 30 kW biomass boiler as well as a 8 m^3 thermal storage tank. The total capacity of the controllable heat sources is 105 kW with added capacity from solar thermal collectors and the storage unit. The heat pumps can work in series so that at first stage water is heated up to 45 °C and at the second stage up to 55 °C. Each house is fitted with a substation with direct connection for space heating and with a heat exchanger for domestic hot water. Radiators are dimensioned for 55/35 °C temperatures. Domestic hot water is supplied at 43 °C. Exhaust air heat recovery systems are connected to the radiators. The houses are equipped with solar panels benefitting from a feed-in tariff. The total budget of the pilot project was £3.65 million. The project was started in 2009 and measurements were carried out from 4/2011 to 3/2012. The measured supply of heat was 49.6 MWh and heat demand 35.7 MWh indicating 28 % heat losses within the system. The average cooling in the system was 20 °C during and 12 °C outside the heating season. Relative monthly heat losses were 60 % at highest in summer and 20 % at lowest in winter.

An energy efficient district heating system in Sonnenberg district of *Ludwigsburg* (Germany) was studied as a case system. Target of the project was to develop a simulation environment for studying integration of distributed renewable heat sources in existing and new systems. The focus was in demand side management of the system, building level heat supply and storage and substation level solutions enabling heat trade within the district heating system (two-way district heating). Partial results of this project will be implemented on a real heating network in the Sonnenberg district. A new low temperature (40/25 °C) extension to the existing (70/40 °C) district heating network has been established. The heat supply consists of a 350 kW gas CHP plant and a 200 kW geothermal heat pump. The project started in 1/2012 and ended in 3/2015.

The Wüstenrot (Germany) case study represents a plus energy community. It consists of 24 mostly single family houses, built almost according to local passive house standard. All buildings have large solar panel systems on the roof-tops and battery storages. The heat demand of the buildings is supplied by decentralised heat pumps and heat storages, which in turn are connected to a centralised geothermal system. This system consists of a cold water district heating network delivering low temperature water from a novel agro-thermal collector to the heat pumps within the buildings. The concept includes activation of agricultural fields as geothermal collectors by ploughing tubes in 2 m depth, the distance between the tubes being 0.5 to 1.0 m. The cold water network can be also used for direct cooling of the buildings in summer time. The system also offers a possibility to use the network as a heat sink for the heat pumps and can utilise heat sources like condensing heat of cooling systems and other sources for highly efficient use of energy. In the demonstration system this concept was demonstrated and analysed by integration of a cooling system in a nearby supermarket. Six to eight buildings were monitored as a first step, extended later to 10 to 15 buildings. Total duration of the monitoring activity was planned to be 3-4 years. Monitoring period started in 3/2014 with the main targets being the demonstration of efficiency, economic viability and system and building energy management as well as the operation of cold water network and agro-thermal collectors. The simulated heat demand for a single house was 20.35 MWh and electricity consumption 4.1 MWh. Measured heat demand for ten months was 27.2 MWh and electricity demand 5.4 MWh. The heat pump COP was 4.8 in average with variation between 2.5 to 6.5. The project ran from 11/2012 to 6/2016.

The case study "Zum Feldlager" in *Kassel* (Germany) is a low temperature district heating system supplying heat for 127 buildings by utilising solar collectors, a centralised ground heat pump with boreholes utilised also as seasonal heat storage. Heat storage is loaded by unglazed solar collectors (swimming pool absorbers as the low-cost option). The buildings are south-facing, specific heat demand being 45 kWh/m^2,a and domestic hot water demand 730 kWh/person/a. Resulting total heat demand is less than 50 kWh/m^2,a. The supply temperature in the district heating network is 40 °C. Connection for the space heating is implemented using heat exchangers, but for the preparation of domestic hot water there are different options; thermal solar collectors (e.g. flat-plate collectors) or an electric heating element complementing district heating. Aim is to find an optimal balance between the economy, use of electric heating, available solar output and distribution heat losses in the network. The project was started 11/2015 and will be ended 8/2017. Total investment is 3.7 M€, including a 1.0 M€ for research.

A district heating system in *Hyvinkää* (Finland) building fair (2013) area was a case study for investigating low temperature district heating. The building fair area consists of 40 consumers within an area of 17 ha. In the implemented system, about half of them are connected to district heating system, the rest having a building specific heating system; e.g. combination of solar PV and collectors or a heat pump. Heat distribution system in the houses can be floor heating, radiators and ventilation based heating. Different options for connecting detached houses to the district heating system were analysed. Houses with solar collectors and a district heating connection were studied as well. Results of simulations showed that the majority of the solar energy is used for the domestic hot water, covering about half of its annual heating needs. Solar energy available for space heating is negligible. Simulations of different district heating network configurations showed the impact of connection rate. For 100 % connection rate case and adequate network structure, the yearly relative heat losses were at a reasonable 10 % level. The low (47 %) connection rate case resulted in 20 % heat losses. Temperature variation and drop within the network especially outside heating season was observed as a peculiarity for a low heat demand district heating system. By-pass arrangements were used to stabilise the flow and temperatures at the cost of increased heat losses, but service pipes still experienced a significant temperature drop. Low temperature variation for distribution resulted in lower heat losses, but approximately doubled consumption of electricity in pumping.

The demonstration project in *Sønderby* (Denmark) was a full scale renovation of a part of an existing district heating system enabling a change from traditional distribution temperatures to a low temperature system. The area included 75 single family houses with the living area of 110 to 212 m^2 each, built in 1997-1998 with under-floor heating systems. The houses originally had hot water tanks for domestic hot water supply (110 l or 150 l in volume). The annual heat consumption of the buildings (based on heating seasons 2004/2005 - 2009/2010) was in range of 5 - 23 MWh/house. In the demonstration project, the old inefficient pipes within the network were replaced by better insulated pipes and the old water storage tank substations were replaced with heat exchanger substations. The low-temperature network in the area uses return pipeline in the medium-temperature network from the neighbouring Taastrup district heating network as heat supply. Measurement data was processed and analysed for a period between 1/2012 and 7/2013. The supply temperature averaged at 48 °C with heat from the return pipeline covering about 80 % of the total heat supply. The remaining heat was supplied by warmer water from the feed pipeline in the neighbouring network. The results showed that it is possible to provide consumers a supply temperature of 50 - 53 °C, which is sufficient for space heating and domestic hot water supply. Heat losses in the old medium temperature system were approximately 41 % while in the new system reached heat losses of 13 – 14 %. The reduction was due to lower supply temperature and better insulation in pipelines. The average supply temperature was 55°C and return temperature is around 40°C, which results an overall cooling of about 15°C. The reduced cooling resulted in greater need for pumping, but in costs this was comparably small in total savings due reduced heat losses. There are several explanations for the higher return temperatures, but the main reasons are too high bypass flow in some substations caused by defective or incorrectly set control valves. One advantage of the concept is the increased available capacity for the existing district heating system without any investment on production.

In *Ulstein* (Norway) fjord district heating is based on utilisation of the “free” heat from the sea by using decentralized heat pumps. A common heat exchanger (s) is utilized to take the heat from the sea. The sea heat with low temperature is then distributed to energy substations. Both heating and cooling are distributed by using the same pipe network without insulation. The local energy substation could be used for one or few buildings. This solution with utilisation of sea heat and decentralized heat pumps is suitable for places located at coast. The total heat supply delivered by the district heating system will be higher than 10 MW within five years. Including the reserve capacity, the plant should deliver about 20 GWh heating and 5 GWh cooling.

Middelfart (Denmark) district heating company has succeeded in lowering supply and return temperatures in their system from an average of 80.6/47.6 °C to 64.6 /40.0 °C during 2015. The district heating network in question is 139 km long in pipe length and services approximately 5000 customers. The heat supply consists of surplus heat from an oil refinery, a CHP plant and a waste incineration plant. The annual heat consumption is approximately 480000 GJ. The district heating company has taken part in the development and testing of software tools that have helped in reducing the also return temperature in district heating network. Furthermore, the company has demonstrated a process that district heating companies can follow when aiming for a low-temperature distribution. During the process the network heat losses in Middelfart have been reduced by 25 % and the economic benefits were estimated to be approximately 5.5 million DKK (0.7 million EUR). The economic savings obtained from the temperature reduction consist of savings due to lower heat loss and savings from a return temperature tariff that is paid to the local heat supplier. The savings have been estimated to be in the size of 110000 DKK/year per °C (14650 €/year per °C) due to heat loss reduction and 380000 DKK/year per °C (50650 €/year per °C) due to the tariff to the heat supplier. The demonstration project has successfully shown how temperature optimisation can be implemented in existing district heating systems, and that it can lead to a significant energy efficiency improvement. The project demonstrates the possibility of including customer installations in the optimisation of the district heating system by monitoring the operation of customer substations, providing service checks for customer installations, and implementing a return temperature tariff that motivates consumers to improve their own internal heat distribution systems.