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The 15th International Symposium on District Heating and Cooling

Low Temperature District Heating for Future Energy Systems

Dietrich Schmidt [a,b]*, Anna Kallert [a,b], Markus Blesl[c], Svend Svendsen[d], Hongwei Li[d], Natasa Nord[e] and Kari Sipilä[f]

[a]*Fraunhofer Institute for Wind Energy and Energy System Technology IWES, Königstor 59, DE-34119 Kassel, Germany*
[b]*Fraunhofer Institute for Building Physics IBP, Gottschalkstrasse 28a, DE-34127 Kassel, Germany*
[c]*University of Stuttgart, Inst. of Energy Economics and Rational Use of Energy, Stuttgart, Germany*
[d]*Technical University of Denmark, Department of Civil Engineering, Lyngby, Denmark*
[e]*Norwegian University of Science and Technology, Dep. of Energy and Process Eng., Trondheim, Norway*
[f]*VTT – The Technical Research Centre of Finland, Department Energy Systems, Espoo, Finland*

Abstract

The building sector is responsible for more than one third of the final energy consumption of societies and produces the largest amount of greenhouse gas emissions of all sectors. This is due to the utilisation of combustion processes of mainly fossil fuels to satisfy the heating demand of the building stock. Low temperature district heating (LTDH) can contribute significantly to a more efficient use of energy resources as well as better integration of renewable energy (e.g. geothermal or solar heat), and surplus heat (e.g. industrial waste heat) into the heating sector. LTDH offers prospects for both the demand side (community building structure) and the supply side (network properties or energy sources). Especially in connection with buildings that demand only low temperatures for space heating. The utilisation of lower temperatures reduces losses in pipelines and can increase the overall efficiency of the total energy chains used in district heating. To optimise the exergy efficiency of community supply systems the LowEx approach can be utilised, which entails matching the quality levels of energy supply and demand in order to optimise the utilisation of high-value resources, such as combustible fuels, and minimising energy losses and irreversible dissipation. The paper presents the international co-operative work in the framework of the International Energy Agency (IEA), the Technology Cooperation Programme on District Heating and Cooling including Combined Heat and Power (DHC|CHP) Annex TS1.

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* Corresponding author. Tel.: +49 561 804 1871; fax: +49 561 804 3187.
E-mail address: dietrich.schmidt@iwes.fraunhofer.de

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1. Introduction

The energy demand of communities for heating and cooling is responsible for more than one third of the final energy consumption in Europe and worldwide. Commonly this energy is provided by different fossil fuel based systems. These combustion processes cause greenhouse gas (GHG) emissions and are regarded as one core challenge in fighting climate change. National and international agreements (e.g. the European 20-20-20-targets or the Kyoto protocol) limit the GHG emissions of the industrialized countries respectively for climate protection. Country specific targets are meant to facilitate the practical implementation of measures. While much has already been achieved, especially regarding the share of renewables in the electricity system, there are still large potentials in the heating and cooling sector and on the community scale. Exploiting these potentials and synergies demands an overall analysis and holistic understanding of conversion processes within communities. Communities are characterized by a wide range of energy demands in different sectors, for instance heating and cooling demands, lighting and ventilation in the building stock. Different energy qualities (exergy) levels are required as heat or cold flows or as electricity and fuels.

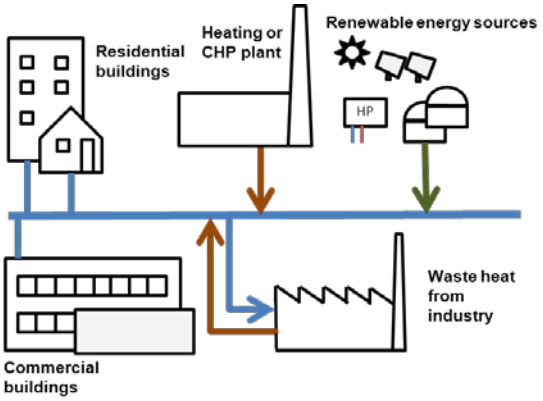

Figure 1. Schematic district heating community supply system with multiple supply options [1].

On community scale especially low temperature district heating offers new possibilities for greater energy efficiency and lower fossil energy consumption. On the demand side, low temperature heat is commonly available as a basis for energy efficient space heating and domestic hot water (DHW) preparation. Low temperature heat can be integrated into district heating through e.g. the use of efficient large scale heat pumps, solar thermal collectors and biomass fired - combined heat and power plants.

Generally, the utilisation of lower temperatures reduces transportation losses in pipelines and can increase the overall efficiency of the total energy chains used in district heating. To achieve maximum efficiencies, not only the district heating and cooling networks and energy conversion need to be optimal, but also the demand side must be fitted to allow the use of low temperatures supplied by the network (e.g. via surface heating system). For this reason, the implementation of solutions based on large shares of renewable energies requires an adaptation of the technical and building infrastructure.

2. Description of the Technical Sector and Low Temperature District Heating

The application of low temperature district heating technology on a community level requires a comprehensive view of all process steps: from heat generation over distribution to consumption within the built environment. The approach includes taking primary, secondary, end and useful energy and exergy into account. This allows an overall optimization of energy and exergy performance of new district heating systems and the assessment of conversion measures (from high temperature DH to low temperature DH) for existing DH systems.

The temperature levels required to heat and cool most building types (residential and non-residential buildings) are generally low (slightly above 23 °C). In the case of the provision of domestic hot water, temperatures in the range of 50 °C should principally be sufficient to avoid the risk from the legionella bacteria. Both renewable and surplus energy sources, which can be harvested very efficiently at low temperature levels, can fulfil this energy demand. On the community scale, synergies are maximised when buildings and building supply systems are regarded as integrated components of an energy system. A number of issues need to be addressed in regard to matching the demand created by space heating (SH) and domestic hot water (DHW) on the building side with the available energy from the supply side in order to develop advanced low temperature heating and high temperature cooling networks.

Latest developments of DH tend towards low-temperature DH schemes and the integration of renewable energy sources [19]. The low-temperature DH which is in focus here, is also called the 4th generation DH.

2.1. Benefits

The use and implementation of low temperature district heating networks offers various benefits:

Utility companies benefit from low temperature district heating by having lower heat losses in the DH networks. Also, they can use plastic piping, which can be more cost effective than conventional DH metal based pipes. The use of low temperature heat allows the integration of additional heat sources into the DH scheme, such as solar thermal collectors, deep geothermal wells and low temperature waste heat. If heat is generated by advanced CHP plants, such as combined-cycle plants, the low temperature of the used heat can lead to a higher electricity generation and therefore improved revenues from energy sales.

Customers benefit in various ways. First of all, the use of district heating ensures a secure supply. Customers do not have to worry about maintenance, fuel supply and optimal operation of heating systems. In the case of low-temperature DHW supply, the use of systems without DHW storage and pipes with small volume from heat exchanger to taps could allow the safe use of DHW at supply temperatures in the range of 50 ºC. In this way, the risk of legionella growth may be minimised without having to resort to higher temperatures.

From an economical point of view, relatively high price stability can be expected due to the use of locally available, renewable, or surplus heat energy sources. An additional advantage of this is a lower dependency on foreign fuel supplies. The high overall system performance that can be achieved by using low temperature DH would lead to reduced resource consumption and therefore lower costs for fuels. This would also increase price stability and could potentially provide heat at very competitive prices.

3. Structure of the DHC Annex TS1 activity

To work on the field of low temperature district heating the IEA DHC activity Annex TS1 is covering work items ranging from the assessment and further development of planning tools, via the collection of suitable DHC technologies and the engagement on the field of the interfaces between the community, the DHC network and the buildings to the analyses of various case studies. Furthermore, dissemination in form of workshops and publications is also covered by the project participants [2].

The IEA DHC Annex TS1 is operated within the frame of the IEA DHC Annex X (e.g. [18]) and IEA DHC Annex XI [2], and thus benefits in highest degree from results developed with this. Furthermore the unrestricted exchange of experience and information is ensured.

4. Results from involved research projects

The goal of the research activities are primarily on reducing of resource consumption (including primary energy) and GHG emissions through overall system optimization and developing new ways of bringing knowledge into practice. First of all identification, demonstration and collection of innovative low temperature district heating systems is in foreground. Here advanced technologies and the interaction between system components are to be demonstrated, as ideas and technologies for reduced network heat loss and improved thermal plant performance or innovative network topologies. Following the collection and identification of promising technologies to meet the goals of future renewable based community energy systems is accomplished.

4.1. Technologies for efficient LTDH supply

In this section selected examples for innovative technologies and advanced system concepts in LTDH are shown. They deal with the issues that need to be addressed for space heating and DHW preparation when using LTDH. Other examples deal with the limitation of higher return temperature when bypassing is avoided. At the end an example for an innovative network topology, the ring network, is discussed.

4.1.1. Space heating control and return temperature

To ensure the consumer thermal comfort while saving energy and reducing network return temperature, the hydronic system in the SH loop need to be properly designed and operated. It was proven that LTDH can meet space heating (SH) demand for both low-energy buildings and existing buildings with floor heating. For existing buildings with old radiators, LTDH can meet SH demand for a certain amount of time of the year, while the supply temperature needs to be increased during cold winter period [11].

Radiator space heating control when applying LTDH in general is the same as when applying traditional DH but there are some points that differentiate. Due to the reduced supply temperatures, it becomes very important to achieve accurate control to limit the flow rate and achieve the design cooling of the supply. To minimize the risk of overflow in radiators thermostatic radiator valves (TRV), a pre-setting function should be used. The purpose of the pre-setting is to limit the maximum flow through the valve to the design demand. Properly set pre-set function will significantly increase the hydraulic balance in the heating loop. To ensure proper operating condition for the TRV's, it is important to install a differential pressure controller. The differential pressure controller will ensure a stable differential pressure at the correct level across the heating installation. To limit the impact of wrong setting of the TRV, a thermostatic return limiter can be installed at the radiators. The purpose of the return limiter is to ensure minimum cooling of the supply. The function of the return limiter is that it closes if the outlet from the radiator is higher than the set point. Most of the year a return temperature of 25 °C can be used but in cold periods a higher temperature has to be accepted. Therefore it is proposed to develop new type of smart thermostatic radiator valve with a return temperature sensor. Such a TRV could secure a low return temperature even if the TRV is not used in an optimal way. In case of floor heating installation, the maximum supply temperature requirements are typically around 40 – 45 °C, which causes no problem for the application of LTDH. As with radiator controls, it is important to apply differential pressure controllers to achieve the optimum operating conditions for the floor heating installation. The flow rate is typically regulated by a room thermostat. To ensure minimum cooling of the supply return temperature limiters should be applied.

4.1.2. DHW preparation for LTDH

A well-designed DHW system should meet several criteria which include consumer comfort, hygiene, energy efficiency. DHW installations should be designed as energy efficient devices. The factors which influence DHW system's energy efficiency include DH supply and return temperature, heat losses from heat exchanger, storage tank and pipes, and thermal bypass set-point.

There are two types of DHW units used for LTDH: instantaneous heat exchanger unit (IHEU) and DH storage tank unit (DHSU). Both IHEU and DHSU can work at low-temperature without the risk of Legionella. Due to the

storage tank buffer effect, DHSU can reduce the connection capacity and thus apply a smaller diameter service pipe at the cost of additional heat loss from the storage tank.

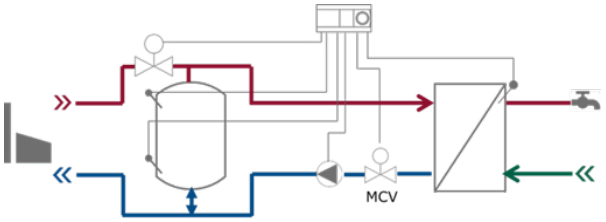

Figure 2. District heating storage unit (DHSU) [24].

On the other hand, IHEU has less standby heat loss and is more compact and less costly.

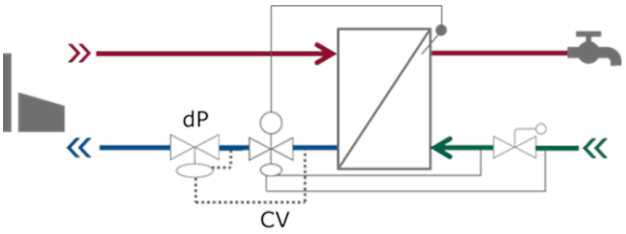

Figure 3. Instantaneous heat exchanger unit (IHEU) [24]

Both units can be applied in centralized and decentralized systems. One of the major barriers to implementing LTDH is the increased Legionella risk with grid supply temperatures close to 50 °C. In [12-13] a review has been made for effective Legionella disinfection solutions to allow DHW system to operate safely at low temperature levels. In general, the Legionella treatment solutions include thermal treatment, chemical treatment, physical treatment and other alternative methods. Such treatments aim at either killing the bacteria presented in the water or prevent the spread of Legionella by limiting the bacteria multiplication within a safety margin. Alternative approaches include electric heating, electric heat tracing, or heat pump which aims to control the DHW supply temperature level. Effective treatment solution concerns not only to meet hygiene and comfort requirement but also to achieve total energy and economic cost saving.

4.1.3. General solutions to avoid bypass flow in service pipes

When the network heating demand becomes low, the required mass flow rate is reduced accordingly. Smaller mass flow rate causes larger water temperature drop along the pipeline due to heat loss to the ground. In non-heating season, the DHW load is low and its demand is intermittent with the total draw-off duration less than 1 hour/day. To keep high thermal comfort, bypass valves are installed at the DHW substation. When there is no draw-off, the DH supply water is bypassed and flows back to the network return line without any cooling, it increases the network return temperature significantly and subsequently increases the network heat loss and decreases the thermal plant performance. This network performance degradation is particularly relevant for LTDH and DH supply to sparse areas. To keep low network return temperature, it should be avoided to having the DH supply water directly mixed with the return water. Several solutions have been suggested to eliminate the service pipe bypass.

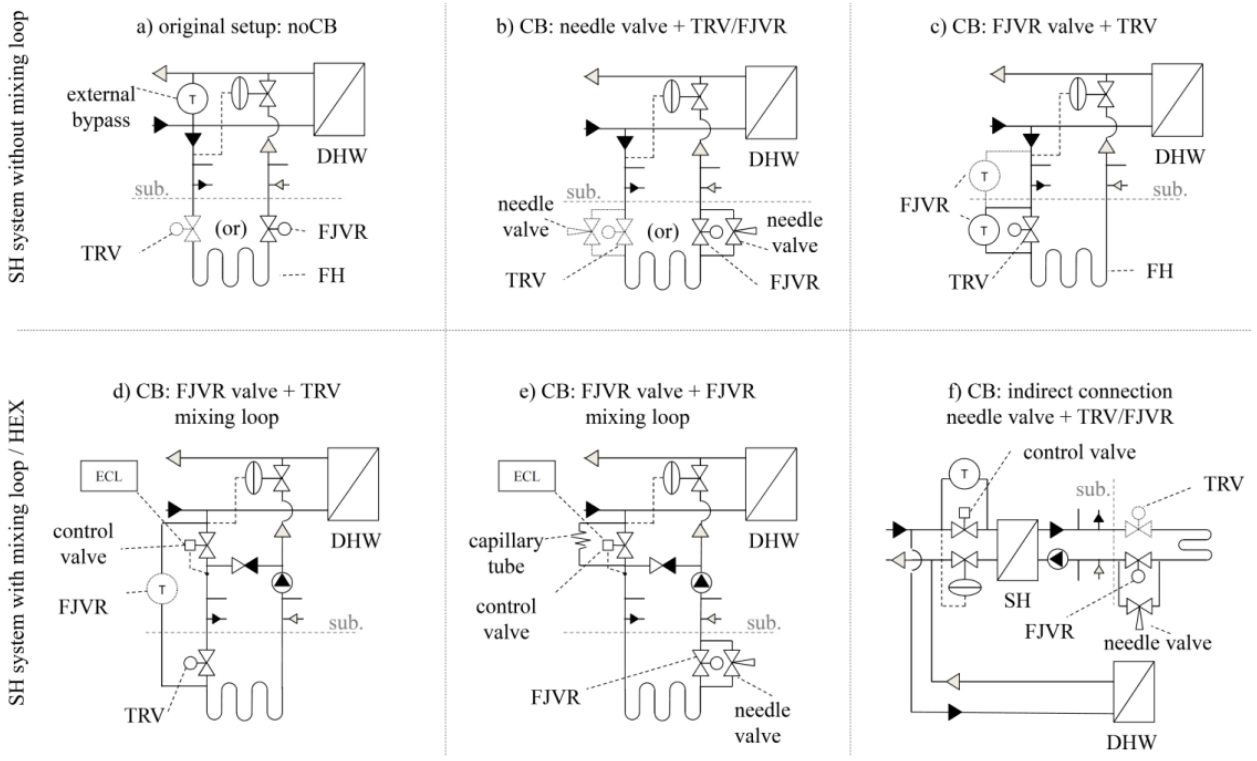

Figure 4. Technical solution for CB implementation [23]. Direct SH system without mixing loop: a) reference case without CB, with traditional external bypass; b) CB realised with a needle valve (installed in parallel to TRV valve on supply pipe or in parallel to FJVR valve on the return pipe of FH loop); c) CB realised with a FJVR bypass valve. Direct SH system with mixing loop: d) CB realised with a FJVR bypass valve; e) CB realised with a needle valve and capillary tube. Indirect SH system: f) CB realised with FJVR bypass valve.

The 1st solution is based on the minimum cooling principle. A recirculation flow in the supply pipe warms up the service pipe and then flows back to the supply pipe in the street through a third recirculation pipe. The recirculation pipe can be a separate DH pipe or one of the pipes in a co-insulated triple pipe. This solution is however likely to create a need for a bypass flow in the street pipes.

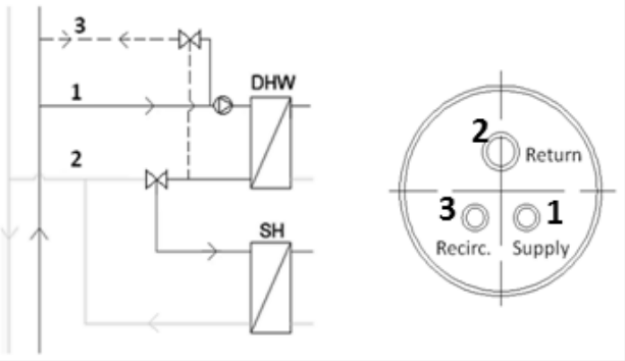

Figure 5. Minimum cooling concept with a triple service pipe [22].

The 2nd solution is based on the maximum cooling principle. After passing through the service pipe, the bypass water is directed to the bathroom floor heating and cooled down to 25 °C before it flows back to the return pipe. The

benefit of this concept is that it uses the bypass flow continuously in the floor heating and replaces an intermittent flow due to a conventional floor heating control.

In case there is no floor heating in the bathroom a towel heater may utilize the bypass flow. Such an application is called 'Comfort Bathroom (CB)' concept (Figure 4). This solution is also securing a flow in the street pipes and therefore does not need a bypass flow in the street pipes.

The 3rd solution is based on electrical supplementary energy. In large buildings with DHW circulation the need to keep the circulation at a minimum of 50 °C results in a high return temperature and requires a district heating supply temperature of more than 55 °C. This can be avoided by use of a heat pump that cools the district heating from 50 °C to 20 °C and heats the circulation loop to 55 °C. Figure 5 shows the schematic to use micro-heat pump to compensate the heat loss in the DHW circulation loop and keep the pipes temperature at 50 °C.

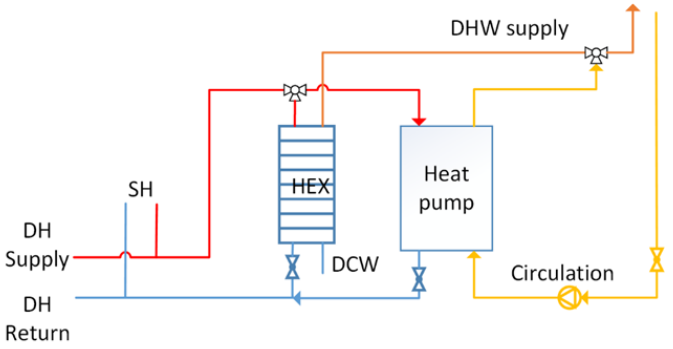

Figure 6. DHW system installing a central heat exchanger combined with heat pump [21].

The benefit of this concept is that the district heating flow to the heat pump also secures the instantaneous DHW heating of the heat exchanger. This solution does not require a bypass in the street pipes.

4.1.4. Example for an innovative district heating network typology: The ring network

In traditional DH network design, the pipe lengths between the heating plant and different consumers vary. The consumers close to the plant has larger available differential pressure, whereas the consumers away from the plant have smaller available differential pressure. In an uncontrolled pipe network, the pressure profile in the system would lead to more water flow through the consumers close to the plant and insufficient water flow through the consumers located far away from the plant. To overcome this, valves are installed in the network to increase the flow resistance and throttle the excess pressure that is available at the consumers close the heat plant until the specified flow to the consumers is achieved. One solution to reduce the valve throttling and potential hydraulic imbalance when the valves were malfunctioned is to apply a ring shape network topology.

Unlike the traditional network, a topology based on ring network equalize the pressure differences between the supply and return pipes, which reduces the impact in case of malfunctioning valves [14]. Figure 7 (a) shows the traditional and ring network in an area of nine detached houses (1-9, DH) and two apartment buildings (1-2, AB) [15]. The idea of the ring topology is to have an equal pipe length for every consumer as presented in Figure 7 (b). The supply line (red line) begins from the heat station (HS) and ends with the last customer, as in the traditional network design. However, the return line (blue line) begins from the first customer and ends at the heat station. In both the supply and return lines, DH water circulates in the same direction. On the contrary, in a traditional DH network design, the return line begins from the last customer and proceeds back to the heat station.

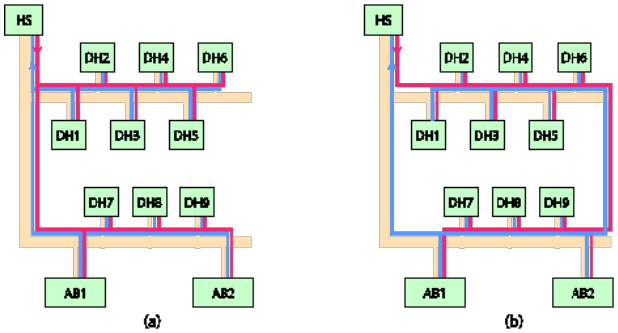

Figure 7. a) Traditional district heating network design and (b) new ring network design [14].

4.2. Methodologies and Planning Tools

Another Objective of the descripted project is the development of a methodology for assessment and the analysis of procedures to optimise local energy systems. Furthermore it includes the development of simplified and advanced tools for design and performance analysis of energy systems within communities, which are based on district heating.

As part of the project the simulation Tool "The Low Exergy – Cluster Analysis Tool (LowEx-CAT)" has been developed. As the integration of low temperature technologies is a main focus of the model, heat grids are also considered in terms of grid temperature, design and optimization of the grid distribution. The goal of the simulation performed by LowEx-CAT is the comparison and evaluation of different energy supply strategies based on district heating technologies. The assessment method developed in the frame of the IEA DHC Annex TS1 aims toward a comprehensive, exergy based evaluation method for local energy systems. The overall objective of the work is the analysis of emerging primary energy and exergy as well as the assessment of CO_2 emissions and economy analysis [16].

4.3. Case studies

While requirements to energy performance of buildings are introduced generally on European and on national levels heat demands of buildings are decreased by applying improved building envelopes and more efficient heat recovery for ventilation systems. Nonetheless LTDH offers a way to supply heat to buildings in an economical feasible and environmental friendly way. The case studies shown in the following are examples where a successful application of new and innovative district heating concepts has been demonstrated [3].

4.3.1. Example: Hyvinkää (FI)

The project at the housing fair area Hyvinkää consists of a number of very low energy buildings and so-called passive houses which are connected to a district heating network. The particular goal for this project is the estimation of the long term performance of innovative district heating systems. So the long-term goal extends to the year 2020 and beyond. A life-cycle analysis on the community-level is carried out. Consequently, an influence of solutions on the community life-cycle emissions can be shown based on these analyses. The aim is also to explore in Finnish climate the boundary conditions and opportunities for the district heating solutions for so-called "nearly zero-energy houses".

During the course of the project the energy consumption in the connected single-family houses and on the DH-system level will be monitored for several years. The results from the measurements will be used to explore short- and long-term fluctuations of power and energy consumption in buildings and to assess their impact on operation of electricity and district heating networks [5].The project aims at the development of special district heating solutions for single-family houses with 2012- and 2021-level (Finish energy standards) of heat consumption. The approach is

based on the life-cycle analysis (LCA) and lifecycle costing (LCE) of the entire energy system (i.e. extending from the indoor space services, through the new district heating network solutions up to the community level energy generation). The potential of using communal waste in energy generation will be assessed, too.

Figure 8. Aerial view Building Exhibition - Hyvinkää (Finland) [17].

4.3.2. Example: Lystrup (DK)

A key challenge for achieving a competitive district heating system of today and in the future is to reduce heat loss in network while today's building regulations demand reduction of heat consumption. So, the ratio between network heat loss and heat consumption in the connected buildings is a main issue. Low temperature district heating offers a solution and is implemented and evaluated in real scale in Lystrup close to Aarhus in Denmark [4]. The goal of this project is to reduce district heating temperature delivered to consumers to 50 °C and connect the buildings in a manner that no reheating is needed to be applied - neither at consumer site nor at district heating site. For the Lystrup project, two types of low-temperature district heating substations and new district heating twin pipes with reduced diameter were developed and tested.

The project consists out of 7 row houses with totally 40 flats where two different sizes of flats are being realised: 89 m² and 109 m² (gross area) with a resulting design heat demand for space heating of 2.2 kW and 2.6 kW respectively. All rooms - except bathrooms – are equipped with low-temperature radiators with a design supply temperature of 50 °C and a return temperature of 25 °C. The bathrooms are supplied with floor heating. To keep the very low supply temperatures district heating water is supplied directly into the building's heating system, no heat exchanger between building heating system and district heating system has been applied [6-7]. The project is a show case that demonstrated that low temperature district heating can be used even in areas with low energy demand while being economically feasible and giving high comfort levels for the connected users [8].

Figure 9. Terraced low energy house in Lystrup [4].

4.3.3. Example: Ludwigsburg (GER)

The urban planning concept for the city quarter of Ludwigsburg entails the design of the local energy supply system by the extension of the main district heating network of the quarter "Sonnenberg" with the aim the use innovative network technology, a so-called low exergy (LowEx) sub grid, and to integrate thermal solar energy into the new grid section.

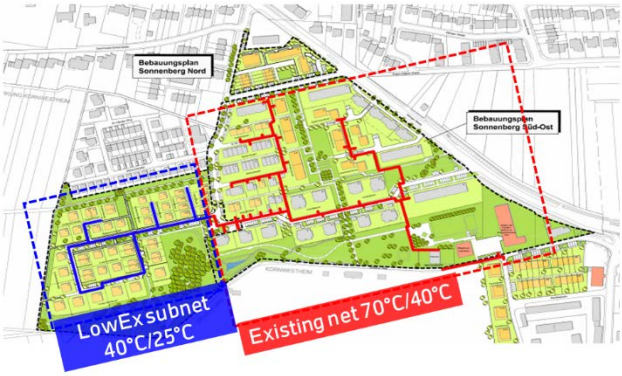

Figure 10. Scheme of net extension in Ludwigsburg Sonnenberg [9].

The project goals for the city of Ludwigsburg are to realise an energy supply concept with a gas-fired cogeneration plant (CHP) of 700 kW_{th} and with a geothermal driven heat pump of 200 kW_{th}. The decentralised heat storages are planned to be located inside the buildings and operated via a smart metering concept with a central control unit [9]. The LowEx network extension is operated with supply temperature at 40 °C from the return temperature of existing network of the city quarter Sonnenberg. This new district heating network, which represents about 30 % of the total network length, is going to be connected to low energy/passive standard buildings. The research project focuses on the demand side management and structure (energy standard of buildings, operation of heaters), the network structure, on the chosen supply concepts and on the storage management.

4.3.4. Example: Kassel Feldlager (GER)

An innovative heat supply concept for the new housing area „Zum Feldlager" of the city of Kassel in Germany with about 130 houses has been set up. The main objectives and challenges with this particular project are the minimization of primary energy consumption, the reduction of CO_2 emissions compared to common supply systems, the reduction of transmission heat losses and the usage of a high share of renewable energy sources for the supply of the about 500 persons living there in near future. So, the heat supply concept has been set up with regard to realise the supply to the entire development area without fossil fuels, such as oil (expensive, water protection area), natural gas (no gas network) or fire wood (fine dust emissions). Use of renewable energy sources such as geothermal and solar energy for low temperature supply has been elaborated [10]. The figure 11 shows the development plan.The supply to the different houses has been planned to be a low temperature heat supply with implementation of intelligent storage systems and thermal load shifting concepts. For the chosen energy concept the houses are supplied by a low temperature district heating grid. For the heat generation both a renewable gas powered combined CHP plant and a low temperature heat generation via a ground coupled (boreholes) central heat pump are investigated separately. For the domestic hot water preparation solar thermal systems with an additional electrical backup heater are planned. The supply temperatures of the low temperature district heating grid is designed to be 40°C, the heat supply for space heating is preferably done via floor heating systems or via low temperature radiators. To increase the efficiency of the heating systems and to optimise the hydraulic integration of the heat generation systems the use of smaller water storage tanks in all buildings is intended. A hygienic preparation of domestic hot water is realised by fresh water stations.

Figure 11. Map of investigated planning area “Zum Feldlager”; representation of the possible supply concept based on a district heating network with central heating plant (CHP plant) [20].

5. Expected Outcome and Results from the Project

The primary deliverable of the presented activities within the annex is an easy to understand and practical, applicable future low temperature district heating design guidebook for key people in communities. It is to contain an executive summary for decision makers. Some key questions for the targeted group of people are:

- What are arguments for taking action in regards to a possible change of the energy system within the community?
- What shall be done with regard to the community’s energy system?
- And, what should not be done?
- Does our community fulfil the conditions for the implementation of low temperature district heating and, if not, what could we improve to allow for this in the future?

These questions will be answered in the guidebook, which is to be focussed at low temperature district heating from a communal, decision makers’ point of view. This will cover issues on how to implement advanced low temperature district heating technology at a community level and how to optimise supply structures to ensure reduced costs for the system solution.

This guidebook will be published preferably both as a book via a publisher, and as an electronic publication. More detailed results, which will be published as appendices or separate reports via the project homepage [2] are intended to cover topics such as:

- Analysis concept and design guidelines with regard to the overall performance. This could include a possible classification of technologies in terms of performance, improvement potential and innovation prospects.
- Analysis framework and open-platform software and tools for community energy system design and performance assessment.
- A collection of best-practice examples and technologies.

- Dissemination of information on demonstration projects.
- Guidelines on how to achieve innovative low temperature systems design, based on analysis and optimisation methods, and derived from scientific studies.

The dissemination of documents and other information is to be focussed at transferring the research results to practitioners.

6. Summary

The IEA DHC Annex TS1 is a framework that promotes the discussion of future heating networks with an international group of experts. The goal is to obtain a common development direction for the wide application of low temperature district heating systems in the near future. The gathered research which is to be collected within this Annex should contribute to establishing DH as a significant factor for the development of 100% renewable energy based communal energy systems in international research communities and in practice. The Annex TS1 is intended to provide solutions for both expanding and rebuilding existing networks and new DH networks. It is strongly targeted at DH technologies and the economic boundary conditions of this field of technology. The area of application under consideration is the usage of low temperature district heating technology on a community level. In connecting the demand side (community/building stock) and the generation side (different energy sources which are suitable to be fed in the DH grids), this technology provides benefits and challenges at various levels. The scientific basis for the development of assessment methods provides the low exergy (LowEx) approach. This approach promotes the efficient and demand adapted supply (e.g. at different temperature levels) and the use of renewable energy sources. As Annex TS1 is a task-shared annex, there will be no individual, separate research projects started within the Annex. The Annex TS1 provides a framework for the exchange of research results from international initiatives and national research projects and allows, in a novel way, the gathering, compiling and presenting of information concerning low temperature district heating. Currently 12 research institutions from 8 countries are participating [2].

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