Low Temperature District Heating as a Key Technology for a Successful Integration of Renewable Heat Sources in our Energy Systems

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Abstract

Low temperature district heating is a heat supply technology for efficient, environmental friendly and cost effective community supply. Moreover, it is recognized as a key technology for transforming and decarbonating heat energy systems by efficient integration of renewable energy sources as solar thermal, geothermal and other waste heat sources.

The results from the international cooperation activity IEA DHC Annex TS2 on “Implementation of Low-Temperature District Heating Systems” provide advice and recipes for obtaining lower network temperatures as well as information on other features to include in existing and new district heating systems (Averfalk et al. 2021). Accomplished by summarizing the economic benefits of low-temperature district heating and gained experiences from early adopters in various urban areas throughout Europe. Lessons learned can be applied in new and expanding district heating systems and are presented in this paper. We discuss economic benefits, temperature levels in buildings, temperature levels in district heating systems, an applied case, competitiveness of low temperature district heating and transition strategies for cities with existing district heating systems.

Keywords: Low temperature district heating, 4th generation DH, energy transition, integration of renewable heat sources

1. Introduction

In many urban areas, district heating systems are used to move heat through pipes from available heat sources to buildings and processes that require heat. Major heat sources include recycled heat from processes that have considerable amounts of residual heat (e.g. thermal power plants and industrial processes generating an excess of heat) but some heat is obtained from renewable energy sources (e.g. solar thermal systems or geothermal wells). Fossil fuels have continued to be used as a primary energy source for combustion. Future district heating systems will have market conditions that differ from those of current systems where the omission of fossil fuels is one.

It is expected that energy efficiency measures will reduce the heat demand and on the supply side, renewables and heat recycling will replace current energy generation systems that rely on processes having fossil fuels as primary energy sources. Hence, future systems will have to use upgraded district heating technology to accomplish decarbonization. An integration of renewable heat sources into the systems is an important step. To ensure efficient, renewable systems, lowering heat distribution temperatures is key.

During the last decade, the collective label ‘fourth-generation district heating’ (4GDH) has been used to describe these enhanced district heating systems. The overarching goal with these systems is to obtain fully decarbonized district heating systems (Frederiksen & Werner 2013). According to the 4th generation definition (Lund et al. 2014), such systems should have the following abilities:

- To supply low-temperature district heating for space heating and hot water preparation
- To distribute heat with low grid losses
- To recycle heat from low-temperature sources

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- To integrate thermal grids into a smart energy system
- To ensure suitable planning, cost and motivation

The transition from traditional district heating systems to completely decarbonized systems will support international, national, and local ambitions for decarbonization by obtaining lower CO_2 emissions. The conclusion from the EU carbon dioxide emissions reduction path is that the rate of change up to 2030 should increase more than five times compared to the previous goal for 2020 (illustrated below). Hence, the increased usage of low temperature district heating networks is important and desirable.

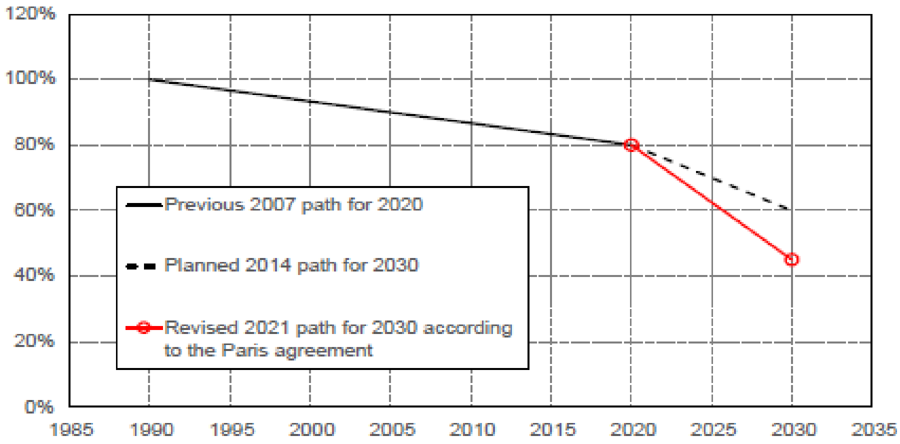

Fig. 1: Three paths for reduction of the EU carbon dioxide emissions until 2020 and 2030.

The IEA-DHC Annex TS2 definition of low temperature district heating applies to all new technological features and concepts using low temperatures, which are considered best available from 2020 onward. As experienced in previous technology generations, a wide diversity of technology choices is expected. Hence, cold district heating systems are also included in our definition of low temperature. The corresponding technology comprises all heat distribution technologies that will utilize supply temperatures below 70 °C as the annual average. 4GDH technology is a family of many different network configurations for heat distribution. Notably, cold and warm networks are siblings in this family of configurations.

2. Gains from low temperature

Heat distribution with supply temperatures below 70 °C will increase the profitability of implementing geothermal heat, heat pumps, industrial excess heat, solar collectors, flue gas condensers, and heat storage options into district heating systems.

At lower distribution temperatures, the economic benefits of renewables and recycled heat are based on the following nine efficiency gains:

1. More heat extracted from geothermal wells since lower temperatures of the geothermal fluid can be returned to the ground.
2. Less electricity used in heat pumps when extracting heat from heat sources with temperatures below the heat distribution temperatures since lower pressures can be applied in the heat pump condensers.
3. More excess heat extracted since lower temperatures of the excess heat carrier will be emitted to the environment.
4. More heat obtained from solar collectors since their heat losses are lower, thereby providing higher conversion efficiencies.
5. More heat recovered from flue gas condensation since the proportion of vaporized water (steam) in the emitted flue gases can be reduced.
6. More electricity generated per unit of heat recycled from steam combined heat and power (CHP) plants since higher power-to-heat ratios are obtained with lower steam pressures in the turbine condensers.
7. Higher heat storage capacities since lower return temperatures can be used in conjunction with high-

temperature outputs from high-temperature heat sources.

8. Lower heat distribution losses with lower average temperature differences between the fluids in heat distribution pipes and the environment.
9. Ability to use plastic pipes instead of steel pipes to save cost.

Additional benefits include a reduced risk of low-cycle fatigue for steel pipes (due to less variation in supply temperatures); smaller temperature drop in the flow direction, allowing for lower supply temperatures from heat supply plants (since less heat will be lost), and a lower risk of scalding during pipe maintenance (lethal accidents have occurred in high-temperature systems).

To quantify the cost reductions related to lower temperatures for various heat supply technologies, a key performance indicator called 'cost reduction gradient' (CRG) is used (Averfalk & Werner, 2020). Examples of CRG for different heat supply technologies are presented in Table 1.

Tab. 1: Overview of assessed economic effects, indicated with the cost reduction gradient (CRG) in euro/(MWh·°C), of reduced system temperatures

Assed heat supply technology (either by itself or dominating in a system)	Cost reduction gradient (CRG) in €/(MWh·K)	
	Investment cases when investment costs are reduced	Existing cases when operating costs are reduced
Low-temperature geothermal heat	0.45-0.74	0.67-0.68
Heat pump	0.41	0.63-0.67
Low-temperature waste heat	0.65	0.51
Solar thermal – flat plate collector	0.35-0.75	Not available
Solar thermal – evacuated tube collector	0.26	Not available
Biomass-boiler with flue gas condensation	Not available	0.10-0.13
Biomass-CHP with back-pressure turbine	Not available	0.10-0.16
Biomass-CHP with extraction turbine	Not available	0.09
Waste-CHP with flue gas condensation	Not available	0.07
Daily storage as tank thermal storage	0.01	0.07
Seasonal storage as pit thermal storage	0.07	0.07
Heat distribution losses	Not available	0-0.13

Table 1 reveals that traditional combustion processes in CHP plants without flue gas condensation have CRGs between 0.10 and 0.13 euro/(MWh·°C). In addition, corresponding CRGs for low-temperature heat sources, such as geothermal, heat pumps and waste heat, are between 0.5 and 0.7 euro/(MWh·°C). Hence, these new low-temperature heat sources have CRGs that are approximately five times higher than those for traditional heat supply.

Therefore, the cost savings for European low-temperature district heating systems is forecasted to be roughly 0.5 euro/(MWh·°C), which results in a total cost reduction potential of 14 billion euro per year, assuming the future annual EU district heat sales of 950 TWh and a temperature reduction of 30 °C. This cost reduction represents a net present value of more than 200 billion euro.

To arrive at low temperatures in the district heating systems both building and network configurations need updating. Lower temperatures in buildings is addressed first (3) then temperatures in networks (4).

3. Lower temperatures inside buildings

In most cases, district heating temperatures are higher than needed to comply with national temperature requirements to control the Legionella risk and typical comfort requirements for space heating. The main obstacles to lower district heating temperatures are the occurrences of simple malfunctions and faults in the district heating substations, and which, therefore, need to be eliminated. Additionally, proper maintenance and automatic fault detection in building substations should be applied in district heating systems (see also Averfalk et al 2021).

Legionella treatment is an area of focus when discussing low-temperature operation (Euroheat & Power, 2008;

HOFOR, 2019). The main risk of Legionella growth is often due to the poor design or operation of internal building installations. Alternatives to thermal treatment of Legionella are available, but in most existing buildings, district heating companies must rely on frequent wireless readings of energy meters to ensure the district heating supply temperature on entry to each customer is high enough to meet national requirements for the thermal treatment of Legionella in domestic hot water installations.

For the long term, energy renovations will enable lower district heating temperatures by reducing the heat demands in existing buildings and, therefore, reducing the space heating temperatures needed in commonly over-sized existing heating systems. The clever design of new heating installations (in existing and new buildings) using robust components will allow for lower temperatures in the future (Østergaard & Svendsen 2016, Østergaard & Svendsen 2017).

Longer thermal lengths in heat exchangers (Averfalk & Werner, 2017). Legionella-safe supply of domestic hot water and the automatic balancing of space heating systems are crucial for low temperature heating. Current, best-available technologies in this regard include externally accessible flat stations for domestic hot water supply and smart return temperature thermostats with automatic balancing functionalities.

For the design of new space heating systems and domestic hot water installations, new standards are needed to address the use of low-temperature heating based on renewable heat sources in the future. Research is needed to develop more solutions to provide Legionella-safe and comfortable domestic hot water without the current high heat requirement (Schmidt et al. 2017).

4. Lower temperatures in heat distribution networks

Five major takeaways have been identified in regards to lower temperatures in heat distribution networks (Averfalk & Werner 2018, Averfalk et al. 2021).

(1) Before investing in any improvement measure, it is necessary to compare customer supply temperatures requirements with the primary supply side temperatures. In some cases, the critical supply temperatures needed by customers and those provided by the district heating network do not match. This happens because the district heating operator does not know the exact supply temperature required by customers and, thus, ensures that the temperature supplied is never below that needed to guarantee comfort.

(2) When replacing existing substations or when designing new ones, heat exchangers with longer thermal lengths should be preferred as these will enable to obtain low supply and return temperatures.

(3) Many systems have already started their transformation to lower temperatures, demonstrating the wide range of possibilities and proven solutions that exist. However, it is important to maintain focus to avoid undermining improvement efforts.

(4) All temperature reduction experiences should be utilised; this means taking advantage of the lessons learned by forerunners and the knowledge transfer that occurs within the district heating community.

(5) Low-temperature systems contribute to the reduction of greenhouse gas emissions. Targeted policy instruments and effective subsidies enable accelerated transformation. It is particularly important to raise awareness and sensitize political decision-makers to the necessity of low-temperature systems, especially given current energy policy frameworks hardly address their importance.

5. Darmstadt applied study

An applied study of temperature reduction in the district heating network at TU Darmstadt’s Campus Lichtwiese served as a showcase of an existing district heating system and is equally applicable to many other district heating systems. The study shows that operational errors within the building heating infrastructure lead to considerable increases in the network temperatures and that problems in a few buildings can have a significant impact on the entire network. In addition, addressing the most critical issues helps to reduce network temperatures considerably, especially on the return side (Oltmanns et al. 2018).

The study also reveals a major barrier: as long as the heat generation in a district heating system is realized via

CHP plants and boilers, reduced network temperatures will not immediately improve cost because many benefits presented in Section 2 do not apply to a fossil- based energy system. Additionally, renewable heat sources, such as geothermal, solar thermal or local waste heat, are low-temperature heat sources, which are neither economically nor energetically feasible in high temperature district heating systems. In a high-temperature district heating network, low-temperature renewable heat can only be integrated using a heat pump at low efficiencies, resulting in high electric energy demands. For an effective transition from fossil-based to renewable district heating, a transition from high-temperature district heating to low-temperature district heating is first necessary (Oltmanns et al. 2020).

6. Competitiveness of low-temperature district heating

Increased operational efficiency from lower system temperatures and optimized technical configurations for low-temperature heat distribution are frequently discussed. Less discussed are the competitive advantages of low-temperature solutions. Therefore, this paper addresses how a stand-alone low-temperature district heating solution, or a combination of conventional district heating and low-temperature solutions can increase the overall competitiveness of the district heating business case. First, an overall business model perspective and a national viewpoint are presented. The discussion is concluded with a more detailed analysis of the heat distribution cost in the low-temperature district heating context.

From an overall perspective, traits in low-temperature district heating business models can be complementary to the conventional district heating model. The selling point of a combination for an existing district heating system or of a stand-alone solution in greenfield investments is that local resources are used, minimizing the carbon footprint. In an era of increased digitalization, engaging in dialogue and establishing long-term relationships are valuable, an upside for the low temperature district heating prosumer relationship (Lygnerud, 2019).

The market maturity of low-temperature district heating is low, and as such, an emphasis is placed on ensuring functional, technical solutions rather than a simultaneous development of the business case. For future installations, tandem development is recommended.

Retaining heat distribution costs in district heating systems at feasible levels is vital to maintain competitiveness. The most significant component of the heat distribution cost is the specific capital cost that is higher in low heat density areas. Second is the cost of the heat distribution loss. But only the latter cost can be considerably reduced by low-temperature heat distribution, since only the ability to use plastic pipes can reduce the capital cost for LTDH.

Furthermore, LTDH should be able to be supplied (input at heating plants) with heat from low-temperature heat sources, which are expected to yield a lower heat generation cost. In low heat density areas, lower heat generation costs and lower heat distribution losses obtained by LTDH cannot completely compensate higher specific capital costs. Hence, it is impossible to increase the total competitiveness of district heating with LTDH in low heat density areas.

7. Practical implementation of low-temperature district heating

The introduction and application of new concepts and technologies, such as low-temperature district heating, often face concerns of feasibility and reliability. The earlier sections discuss measures to be taken on a building and system level and show the various technical and economic benefits of low-temperature district heating. This sections highlights that many innovative low-temperature district heating systems have already been built and operate successfully.

The demonstrators considered in this paper include various system configurations and different boundary conditions such as already realized low temperature community energy system concepts as well as planned or designed systems. Furthermore, projects showing an innovative use or operation of buildings, advanced technologies and the interaction between components within a system are included.

In total six classes of demonstrators have been identified. As they are:

- realized demonstration project on existing or conversion areas with an existing heating network
- realized demonstration project on existing or conversion areas with a new heating network
- realized demonstration projects on new constructed areas with a new heating network
- simulation and design studies on areas
- realized demonstration projects on the single building scale
- demonstrators on a laboratory scale

15 selected demonstration activities out of 40 within Europe were analyzed in detail. Cases from other countries are included in the guidebook (Averflak et al. 2021). Figure 1 shows all collected demonstration cases within Europe. Additionally to that, a gross list with approx. 150 realized low temperature district heating systems all over the world were collected (see Averfalk et al. 2021). This impressively proves the feasibility and applicability of LTDH technology.

★Cases analysed in detail and presented (see table 2)
●Cases analysed in detail in this project (see Averfalk et al 2021)
○ Cases described in the gross list of low-temperature initiatives (see Averfalk et al 2021)

Fig. 1: Locations of the regarded demonstrator cases. © Fraunhofer IEE, own representation. Map taken from Eurostat: https://ec.europa.eu/eurostat

Tab. 2: Selected and described demonstrators for the implementation of low temperature district heating systems.

City and Area	*Country*	*Class*	*Temp. level*[1]	*Heat Supply*	*System size*[2]
Gleisdorf Transition strategy	Austria		Warm (80/50°C)	biomass & gas boilers, solar collectors	Medium (6,374 m)
Wüstenrot Weihenbronn	Germany		Warm (70/40°C)	Biomass boiler, solar collectors	Micro (371 m)
Darmstadt Lichtwiese	Germany		Warm (88/58°C)	District heating-cooling with absorption chiller	Medium (4,200 m)
Heerlen Parkstad Limburg	The Netherlands		Cold (28/16°C)	Mine water	Big (40 km)
Zürich FGZ	Switzerland		Cold (<25°C)	Data centre	Small (2,125 m)
Salzburg Lehen	Austria		Warm (65/40°C)	Solar collectors, heat pump, district heating	Small (680 m)
Graz Reininghaus	Austria		Warm (69/43°C)	Industrial excess heat, heat pump	Medium (6,000 m)
Braunschweig Rautheim	Germany		Warm (70/40°C)	Data centre	Small (2,750 m)
Lund Brunnshög	Sweden		Warm (65/35°C)	Excess heat from research facilities	Medium (6.5 km)
Kassel Feldlager	Germany		Cold (40/30°C)	ATES, GSHP and solar collectors	Medium (5.7 km)
Bamberg Lagarde	Germany		Cold & Warm (1- -2/80-50)	GSHP, sewage, CHP, district heating	Small (1,200 m)
Bjerringbo Tyttebærvej	Denmark		Warm (50/30°C)	Industrial excess heat, ATES, heat pump	n.a.
Viborg Multifamily home	Denmark		Warm (68/40°C)	District heating	Big (344.8 km)
Frederiksberg Multifamily home	Denmark		Warm (80/48°C)	District heating	Big (181.5 km)
Kassel District LAB	Germany		Cold & warm (5-130/varying°C)	Heat pump, boiler	Micro (390 m)

Core objective for the description of case studies was to identify and collect innovative demonstration concepts as examples of success stories for communities interested in developing LTDH systems. There was a total of 40 case studies from Austria, Denmark, Germany, Ireland, Norway, Switzerland, Sweden, The Netherlands and United Kingdom (see Averfalk et al. 2021). The district heating systems were of very different sizes, from miniature to city wide systems. Network lengths were from approx. 370 m to more than 340 km. The connected buildings were detached, terraced and block houses, and many 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 cold and low-temperature systems, varying from -2 to 88 °C in supply and 16 to 58 °C in return. Savings and increased efficiencies were observed in every case studied.

Particularly from the displayed case studies, the following main conclusions can be drawn:

- From a technical point of view, the large variety of system configurations shows the flexibility in the implementation and realization of low-temperature district heating systems. For the operation, a sufficient monitoring and management system secures the success of the project. For the integration of multiple heat sources and more complicated systems, a wider digitalization of the processes is needed.
- The regulatory boundary conditions are not always beneficial. So, for example, the integration of geothermal heat requires a long (or too long) approval process, which can potentially derail the implementation. Furthermore, real cross-sectoral energy systems are not foreseen with today’s rules, which makes a realization complicated.

[1] Typical/mean supply and return temperature
[2] Trench length

- The cases clearly show that a high connection rate and support from the customer could be gained when the system is owned by the municipality or a cooperative.
- From a business point of view with the above-mentioned ownership issue, interest rates might be lower, and long payback times are manageable. Some cases show that a transition to low-temperature district heating systems is economically feasible; some cases indicate the price level for the heat supply could be up to 10% lower compared to a conventional solution, even without accounting for future damage cost from global warming.

These conclusions prove that low-temperature district heating is a market-ready heat supply technology that can operate under various boundary conditions. Furthermore, case experiences show the need for digitalization measures to secure a successful operation under the new boundary conditions, such as the integration of fluctuating renewable or waste heat sources or changed network (bidirectional) operation.

8. Transition strategies

The essence of conversion, transformation and transition is that all humans are capable of profound change. Required changes in our communities can be initiated, communicated, and implemented by three steps – (1) visions, (2) strategies and (3) planning measures. Changes to our energy system should also be identified at all levels in our global community. Although changes are necessary and inevitable in all areas, they are often accompanied by concerns. The eighth chapter shows how local transition strategies have addressed these apprehensions in some urban areas.

Adopted visions, strategies, and planning measures from five urban areas are presented when the heat distribution temperature issue is properly identified within the decarbonization context (Stadt Gleisdorf, 2012, AEE INTEC, 2020, Abildgaard, 2017, Regieringsrat des Kantons Basel-Stadt, 2017, Küng, 2019, Secretariat du Grand Conseil, 2013, Quiquerez et al. 2017, Durandeux, 2019, Henke et al. 2015, Frey & Miller, 2017, Stadtwerke München, 2017, Theis, 2019). The three steps are vital to implementing district heating and cooling systems based on renewable or recycled heat or cold in every urban area. Additional university examples are briefly provided since some universities are forerunners in low-temperature district heating.

The major conclusions concerning visions, strategies, and planning measures within the local transition strategies are the following:

- Lower distribution temperatures are necessary in transition strategies for the decarbonization of district heating systems.
- Cooperation with research organizations should be considered when new technologies are implemented in local district heating systems.
- University campuses are often forerunners with new technologies for heat distribution.

9. Conclusions

Conclusions about technological development, nontechnical aspects, and policy implications, along with recommendations, are summarized here.

Tangible proper technologies and methods are available for the implementation of low-temperature district heating. Early adopters have tested and implemented lower temperatures in existing and new heat distribution networks. Building owners can and should adopt the technology now for the utilization of lower temperatures in the future. Reductions of specific heat demands will also facilitate lower temperatures. However, current technologies and methods can be further elaborated and refined by research and development.

The primary non-technical barrier to undertaking a low-temperature district heating investment is the resistance to change. One major factor that can explain the limited interest in future-proof low-temperature district heating technology is that the risk of limited heat supply in 2050, since current fossil fuels will not be available, has not yet become apparent for most end users and heat providers.

The economic benefit of low-temperature district heating can reduce the levelized cost of heat from future district heating systems, but the savings in current systems is limited. Hence, this advantage is not now strong enough alone to encourage a transition towards more decarbonized district heating systems. Carbon pricing or other efficient policy drivers must be used as strong parallel economic drivers for incentivizing decarbonization. In addition, old institutional rules require proper revision for better alignment with low-temperature district heating.

Low-temperature district heating is easier to implement than many people fear, but adequate organization is required. In the transition work, long term visions express the future direction for the decarbonization, short and long term strategies identify what to do, and short and long term planning measures outline the steps to take.

The three main conclusions from the published guidebook from IEA DHC Annex TS2 (Averfalk et al 2021) are the following:

- Low-temperature district heating together with expected national carbon pricing schemes are major economic drivers for the decarbonization of the European district heating systems.
- The implementations of low-temperature district heating are possible since several early adopters have provided clear evidence for its suitability.
- However, the hurdles to start the transition are old habits and lock-in effects from application of current technology together with a lack of understanding of how to efficiently link stakeholders to each other.

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