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Chapter

Recent Progress in District Heating with Emphasis on Low-Temperature Systems

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Abstract

District heating plays an important role in future sustainable energy system by integrating any available heat source, including waste heat and renewable heat sources such as geothermal or solar heat. The low-temperature district heating system is the latest generation of district heating. It was introduced less than ten years ago in adaption to the need for lower heat demand of energy-efficient buildings. The low-temperature district heating system provides an infrastructure for a higher share of renewable energy sources while reduces heat loss in pipes. Several small-scale projects were commissioned since the introduction of the technology, and many existing district heating systems are in the process of adaptation. The recent progress of low-temperature district heating systems has been discussed here. First, the fundamental knowledge that is required to understand the main advantages of a low-temperature district heating system was explained briefly. Then the most recent and important projects were discussed with emphasis on solar and geothermal district heating systems. The results of case studies show that the low-temperature solution has the lowest capital costs and has a unique position to be the primary source for building heating demand.

Keywords: district heating, low-temperature, smart heat networks, microgrid, distributed generation, community energy, solar district heating, geothermal, energy storage

1. Introduction

Traditionally, the heating in residential and commercial buildings has been provided by individual systems such as furnaces and boilers. These methods were not only less efficient but also have been responsible for substantial amounts of greenhouse gases. District Heating (DH) systems are simply systems that are powered by a central heat source instead of by multiple individual heat sources for each building. By centralizing the heating in larger systems, it is possible to supply many buildings from one or more sources, such as Combined Heat and Power (CHP), Waste-to-Energy (WtE), and Renewable Energy Sources (RES). Several cities in Europe and throughout the world have begun to shift to DH systems. **Figure 1** provides the percentage of supplied energy with DH and the share of RES in the existing DH systems. In aggregated 28 European countries, there are more than 10,000 DH systems, which provide 9% of heating in the residential sector, 10% in the service sector, and

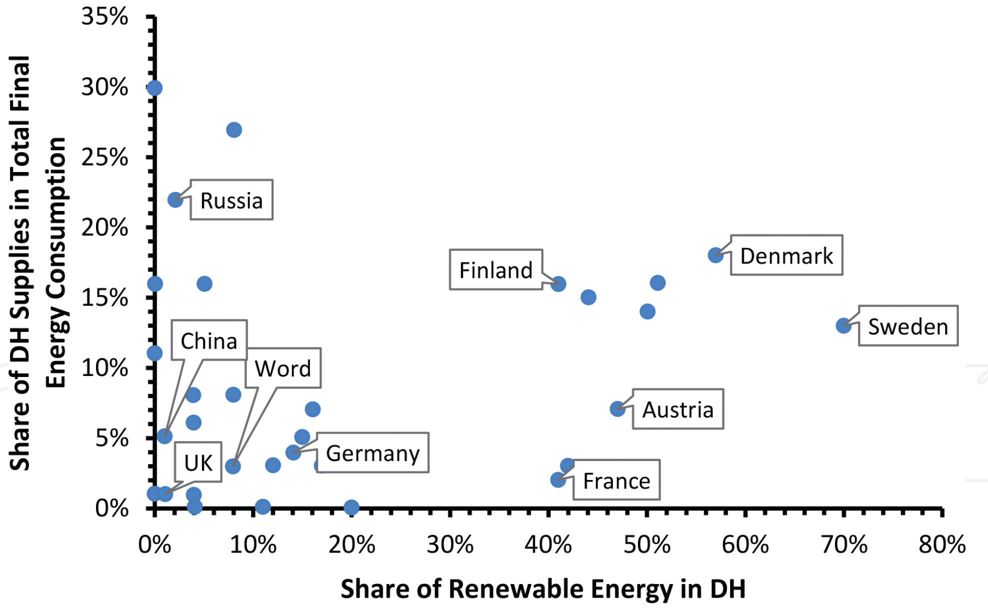

Figure 1.
Share of renewable energy in district heating networks, 2018 [1].

8% of the heating demands in the industrial sector [2]. District heating technology is less common in the United States and Canada than in Europe. According to the International District Energy Association's (IDEA) database, about 660 district energy systems are operating in the United States, and approximately 80 are working in Canada [3]. District heating is suitable for networks of all sizes, from two buildings up to a community, and even cities.

District heating systems have been evolving with a trend towards lowering supply temperatures and introducing different energy sources. Studies revealed that the 4th or 5th generation of district heating systems, along with thermal storage, is more feasible, fuel-efficient, and cheaper than individual solutions in areas with high urban density [4, 5]. The central concept of fourth-generation is a smart thermal grid. Smart thermal grids are defined as a network of pipes, connecting buildings in a neighborhood, small town, or a large metropolitan so they can be served from centralized plants or distributed heating sources, including individual contributions from the connected buildings [6]. The fifth-generation district heating has a network with temperature as close as to ambient ground temperature. In a recent review article [5], Buffa et al. studied more than forty DH systems that belong to the 5th generation. Most of these reviewed cases use shallow geothermal or groundwater as the heat source. In low-temperature networks, heat loss to the ground is eliminated, and the cost of distribution circuit is radically reduced.

If the DH supply temperature is 25°C and less, it cannot be used directly for space heating or domestic hot water (DHW). An electric heater or a booster heat pump is required to raise the temperature. A heat pump extracts heat from a low-temperature medium (e.g., DH supply) and delivers it to a medium on a higher temperature (e.g., building). In this article, a DH system with a supply temperature less than 60°C is called Low-Temperature District Heating (LTDH); thus, both 4th and 5th generations are categorized as LTDH. **Figure 2** shows the evolution of DH systems.

Several mediums can be used as heat sources of low-temperature DH. However, not all sources are universally available or have the same temperature level. Among the potential heat sources, geothermal heat was identified as the most promising source [7]. Direct use of geothermal energy in the DH system is one of the oldest and also the most common form of renewable energy. Space heating, bathing/swimming, agricultural applications, fish farming, snow melting, and industrial process are examples of direct geothermal energy utilization. Most direct uses utilize geothermal fluids in a low (30–90°C) and medium (90–150°C) temperature. The application of very low (less than 30°C) reservoir temperature has been introduced recently and initiated many types of research and case studies [8]. In a low-temperature geothermal, the thermal energy extracts from a shallow depth either by borehole heat exchangers or with the help of heat pumps. These heat pumps often are called ground-source or geothermal heat pumps (GSHP). According to WGC2020, 88 countries utilize geothermal energy for direct heat applications with significant growth in the GSHP market worldwide. About 6.46 million GSHP units have been installed in 2019, which shows a 54% increase compared to the number of installations in 2015 [9]. The trend on GSHP, as opposed to the other geothermal energy

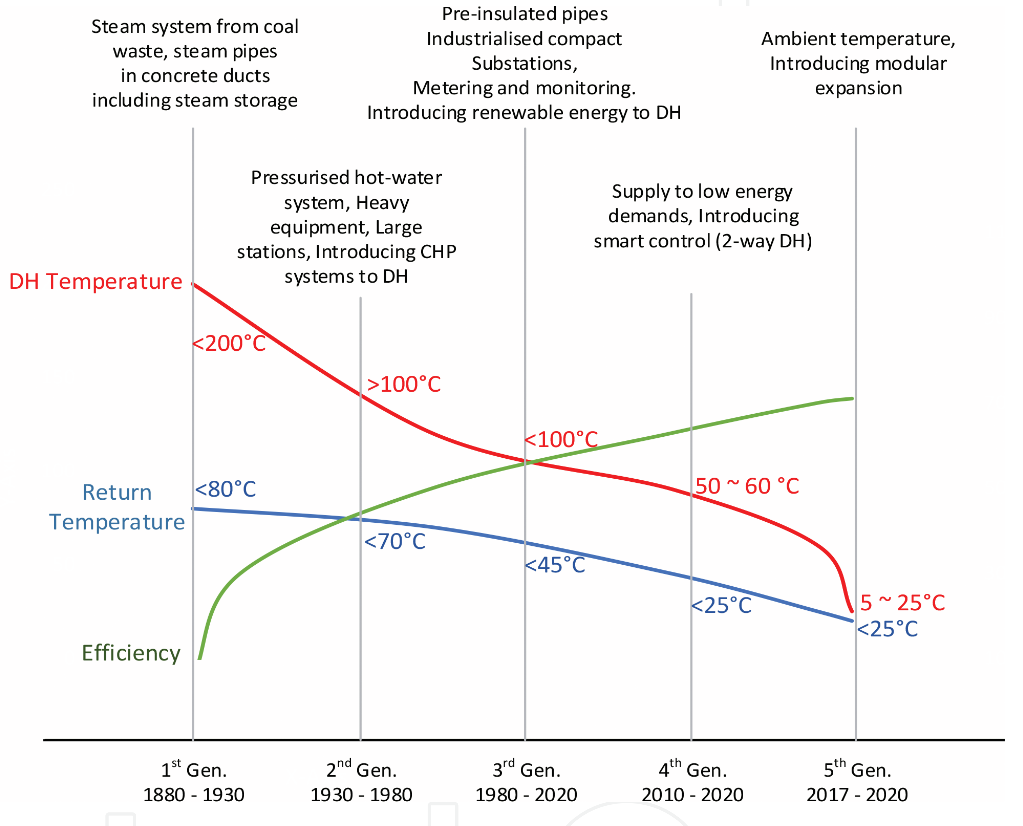

Figure 2.
Historical development of DH systems.

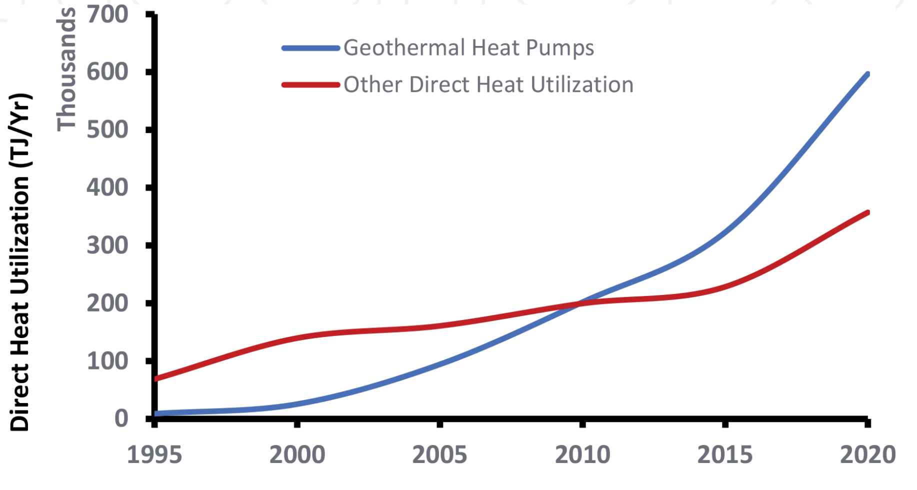

Figure 3.
Direct utilization of geothermal energy [9].

applications, has been shown in **Figure 3**. The size of installed GSHPs ranges from a couple of kilowatts for residential heating to large units over 150 kW for commercial and institutional installations. However, it is difficult to find out whether these GSHP have been installed in DH systems or not. According to the IEA, the heat supplied through DH increased by 18% in 2019 compared with 2015 [10]. Therefore, it can be concluded that most of the GSHPs were not installed in DH networks. In a comparative analysis, Lee et al. briefly discussed the advantages of DH over individual GSHP [11]. In another study, Shin et al. proposed the integration of GSHP on a shared loop to increase the system efficiency and improve the heat demand control [12].

One of the first LTDH projects with geothermal heat source is the residential area in Berlin-Zehlendorf, with 22 houses, 135 apartments, and a total of 21,000 m^2 floor space that was completed in 2016. The network temperature is approximately 10°C so that no heat is wasted, and no expensive pipe insulation is required. Decentralized heat pumps extract heat from the network and supply heat energy to the houses. Heat is provided by a CHP plant and borehole heat exchangers [13].

Another example is the city of Plymouth in the UK that will be adapted to a low-temperature DH. The supply DH temperature in the primary energy sharing network is designed between 2°C and 25°C, and the return temperature will not be higher than 25°C throughout the year. The end-users will equip with DHW booster heat pumps to increase DHW temperature to 50°C. Heat sources of the DH network will be groundwater, sea, and low-grade waste heat [14]. This particular project is one of the HeatNet pilot studies. HeatNet is an EU Interreg project to address the challenge of reducing CO2 emissions across northwest Europe by creating an integrated transnational approach to the supply of renewable and low carbon heat. The project's construction started in 2020, and the first stage of the project is planned to commission in 2021 [15].

DH systems' design requires a case-by-case approach to fully take advantage of the available local energy and identify end-users heating demand profiles. Therefore, DH systems are always site-specific and vary from one location to another, considering the size, climate, heat sources, and technologies. DH system can also be classified by size, which defines by:

- Length of the piping system (trench length)
- Number of substations
- Number of connected consumers
- Amount of investment costs
- Complexity (e.g., number of heat sources)
- Distributed heat and size of heat sources
- Spatial coverage area

Copenhagen is an excellent example of an extensive DH system. The DH system was started with one small local network in 1903, and now 98% of the city is supplied by district heating. The system serves 75 million m^2 of net floor area. The annual heat sale is 8500 GWh, and the system capacity is 10,000 GWh. The backbone of the system is a 160 km long distribution network and 3 x 24,000 m^3 heat storage tanks [16].

Small DH systems are more suitable for residential communities and small to medium size industries with excess heat. In some cases, a small DH system may connect to a large DH grid. However, the general idea is to promote individual piping networks that connect a relatively small number of consumers.

Micro heating grids are a relatively new concept characterized by advanced central control to share the resources and interact with the DH network [17]. One advantage of microgrids is that these systems could be built more straightforward and faster because of the small number of customers, without lengthy procedures.

DH systems can be categorized according to the heat production units' location into centralized and decentralized systems. Most DH systems were designed based on one of a few centralized heat generators in the past. By introducing the 4th and 5th generation, a growing number of decentralized systems use heat from various decentralized facilities. A centralized approach is best suited for upgrades or expansions of an existing district DH system. The distributed approach is recommended for a new and sparse area with relatively low load density. As such, the cost of constructing a new district energy network outweighs the other benefits of a centralized district energy system.

Nonetheless, all DH system encompasses:

- Heat sources
- Distribution network
- Consumer interconnection
- Heat storage

Despite the well-known advantages of LTDH, there are a limited number of literature reviews. The majority of the reviews only focus on a specific aspect of the district heating systems, such as modeling [18] or system flexibility [19]. In order to address the lack of a comprehensive literature review, this article provides a preliminary review of LTDH systems. The information was collected through the review of international success stories and recent academic literatures. In the following sections, the progress of low-temperature district heating systems is reviewed with respect to heat sources and distribution networks. Geothermal heat and solar radiation are the most viable types of heat source, therefore both of them are discussed in details. The cost of DH and aspects of network design are carried out by the review of typical LTDH systems.

2. Heat sources

One of the advantages of LTDH is diversified heat sources. Studies and pilot projects have shown that a DH temperature of less than 60°C significantly increases the potential to utilize waste heat of different industrial processes and cooling processes (e.g., supermarkets or data centers waste heat). Heat can be supplied by various sources such as:

- Thermal powerplants
- Waste-to-Energy (WtE) facilities (e.g., Incinerators)

- Industrial processes (i.e., Waste heat recovery system)
- Sewerage water
- Commercial buildings (e.g., Datacenter)
- Boilers (Gas fired, Electric, biomass or biogas fuelled)
- CHP plants
- Geothermal sources
- Heat pumps
- Fuel cells
- Solar thermal arrays

Heat recovery from industrial processes is not a new concept for DH. It has been applied in some countries such as Russia, Sweden, and Germany for many years in high-temperature DH networks [20]. An excellent example of the waste heat recovery is MEMPHIS's research project under IEA DHC Annex XII [21]. As part of this project, an open-source map[1] has been developed to assess waste heat potential from the industry and business sector and sewer networks. Some studies recommend adapting the industrial process heat recovery systems for LTDH [22, 23]. However, the main barrier is the economic risk associated with these heat recovery systems, if the primary industrial activities close down.

Renewable heating sources, such as solar and geothermal, are emerging in most countries. As an example, the European statistical data shows that the energy supply becomes increasingly renewable. They committed to have 100% renewable resources by 2050 [24]. A review of renewable energy sources for district heating was published recently by Olsthoorn et al. [25]. However, only the two renewable heat sources of solar and geothermal have been discussed here.

2.1 Solar district heating

Danish district heating is the most innovative district heating sector in the world. More than 1.3 million m^2 solar district heating (SDH) plants are in operation in Denmark[2]. Moreover, more than 70% of the large solar district heating plants worldwide are constructed in Denmark [26]. Since 2009, the European Union has supported three multinational SDH projects regarding solar district heating plants' market development. One of them, called "SDHp2m", addressed market uptake challenges for broader use of SDH [27]. Most of the DHp2m data are all freely available and can provide a basis for SDH feasibility evaluations.

Solar irradiance is the amount of solar radiation obtained per unit area by a given surface (W/m^2) in a location. This irradiance varies month by month, depending on the seasons. It also varies throughout the day, depending on the sun's position in the sky and the weather. The solar efficiency is the ratio between solar heat production and the total solar irradiation on the collector plane. This ratio is a performance measure on how well the system utilizes the available solar radiation. Solar efficiency mostly depends on operating conditions, such as temperature levels and solar

1 http://cities.ait.ac.at/uilab/udb/home/memphis/

2 http://solarheatdata.eu/

radiation intensity. Hence, low solar efficiency is not necessarily caused by a poorly working system or inefficient collectors [28]. A schematic of the SDH was shown in **Figure 4**. The monthly average solar efficiency and the total heat generated from an SDH in Vojens, Denmark were presented in **Figures 5** and **6**, respectively. This SDH commissioned in 2012 with an effective aperture area of 17,500 m^2, and a 3000 m^3 storage tank. The plant went to an expansion in 2014 and 2015, which end up with 5439 solar collectors (area of 70,000 m^2), and a thermal pit storage capacity of 200,000 m^3 for seasonal storing of excess solar heat [29].

The investment cost and the operating costs are the critical factors of the planning. The operating cost depends on the location and system components. As a rule of thumb, an annual rate of 0.54 €/MWh is considered in SDHp2m or 0.0405 €/m^2 (collector area) in the Danish Technology Data catalog[3]. It is expected that the system capital cost per MWh decreases by increasing the DH size. The capital cost is a combination of equipment costs (i.e., solar collectors, piping system, circulation pumps) and installation. **Figure 7** provides an estimation for solar collectors as per the SDHp2m study and the Danish Technology Data catalog.

Seasonal heat storage is effectively increasing solar heating in an SDH system. The ratio of heat provide by solar collectors in a typical SDH system is around 20%, if there is no seasonal heat storage [30]. The seasonal heat storage can increase the solar heating share to 30–50% [26]. Four different options of long-term or seasonal heat storage are available:

- PTES, Pit Thermal Energy Storage
- BTES, Borehole Thermal Energy Storage, ground storage with closed loops
- ATES, Aquifer Thermal Energy Storage, ground storage with open loops
- TTES, Tank Thermal Energy Storage

Pit Thermal Energy Storages (PTES) are a relatively cheap storage technology, which has been developed mostly in Denmark (e.g., Marstal 75,000 m^3, Dronninglund 60,00 m^3) in combination with solar thermal plants. The limitations and advantages of PTES briefly are shown in **Figure 8**. The physical footprint of PTES is significant; therefore, the feasibility of PTES depends on the local conditions. Borehole Thermal Energy Storage (BTES) is a relatively new technology. In a BTES, the heat directly stores underground through vertical boreholes and U-pipes. The thermal flow direction is from the center to the sides to obtain high temperatures in the center and lower at the storage boundaries during the charging period. The flow direction during the discharge is reversed. The upper surface of BTES is usually insulated to minimize the heat loss. The ground can store between 15 to 30 kWh/m^3, which is much lower than the PTES capacity of 30 to 80 kWh/m^3 [32]. The Okotoks solar district heating system that is located in Alberta, Canada, is an example of BTES. This DH system supplies more than 90% of space heating to 52 detached energy-efficient homes since 2007 [33]. An aquifer is an underground water reservoir. An Aquifer Thermal Energy Storage (ATES) utilizes a mixture of natural water and ground to store the heat. In an ATES, two wells, one warm and one cold, are drilled into the aquifer to extract and inject the groundwater. Another type of thermal storage which is very similar to PTES is called Tank Thermal Energy Storage (TTES). TTES is cylindrical steel or concrete tank placed on the ground and used daily or on a short-time storage basis. A number of guidelines and fact sheets are available through the SHC Task-45 framework. This

[3] https://ens.dk/en/our-services/projections-and-models/technology-data

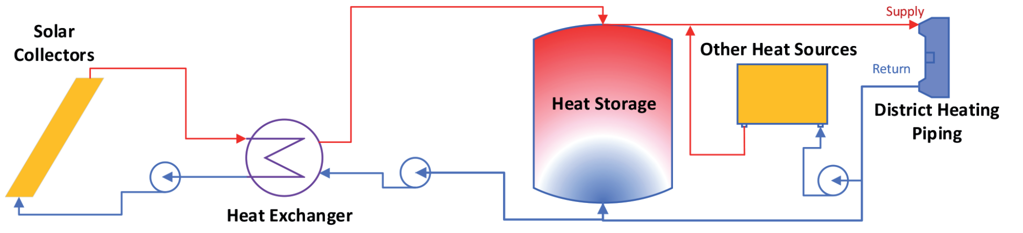

Figure 4.
Schematic of a solar DH system.

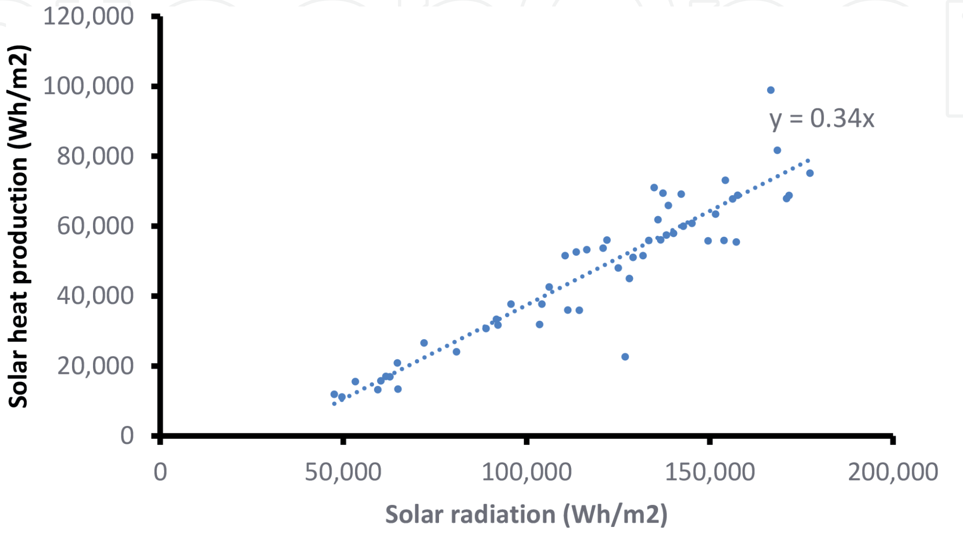

Figure 5.
Input/output plot of monthly measured values of Vojens district heating.

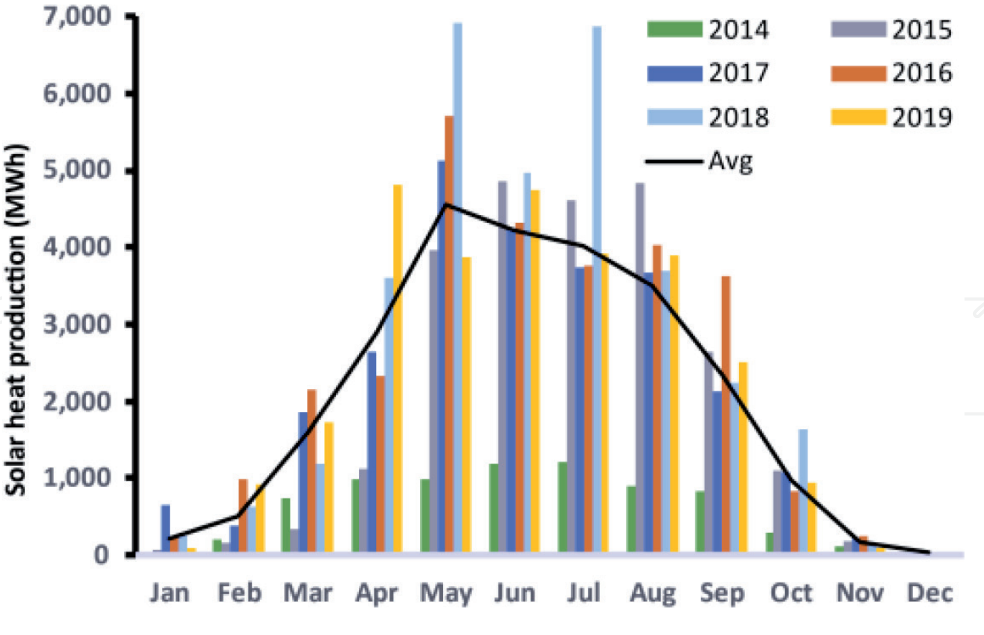

Figure 6.
Solar heat production of Vojens district heating.

framework was completed in 2014 to assist a sustainable market for large solar heating and cooling system [34].

The investment cost for design, construction, and commissioning of several European thermal storages are available (**Figure 9**). Since the design and construction of thermal energy storage systems are site-specific, **Figure 9** provides an approximate investment per storage capacity. In addition to SHC Task-45, some

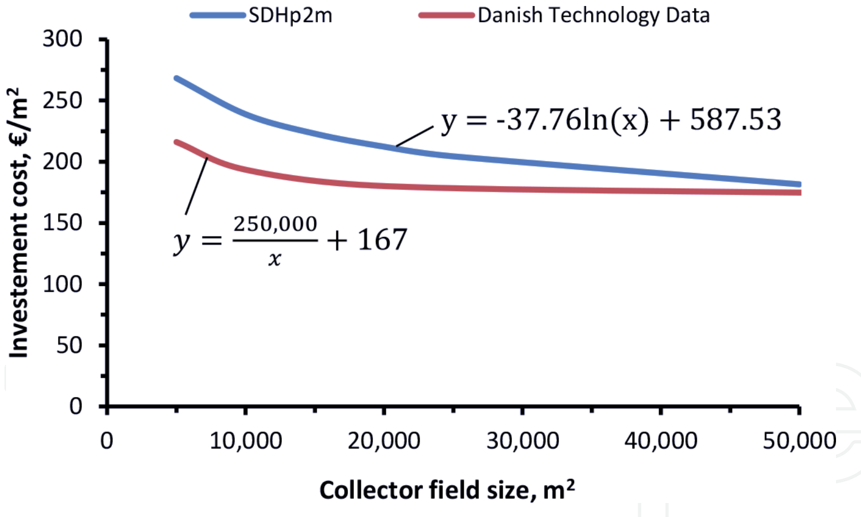

Figure 7.
Investment cost of solar collectors.

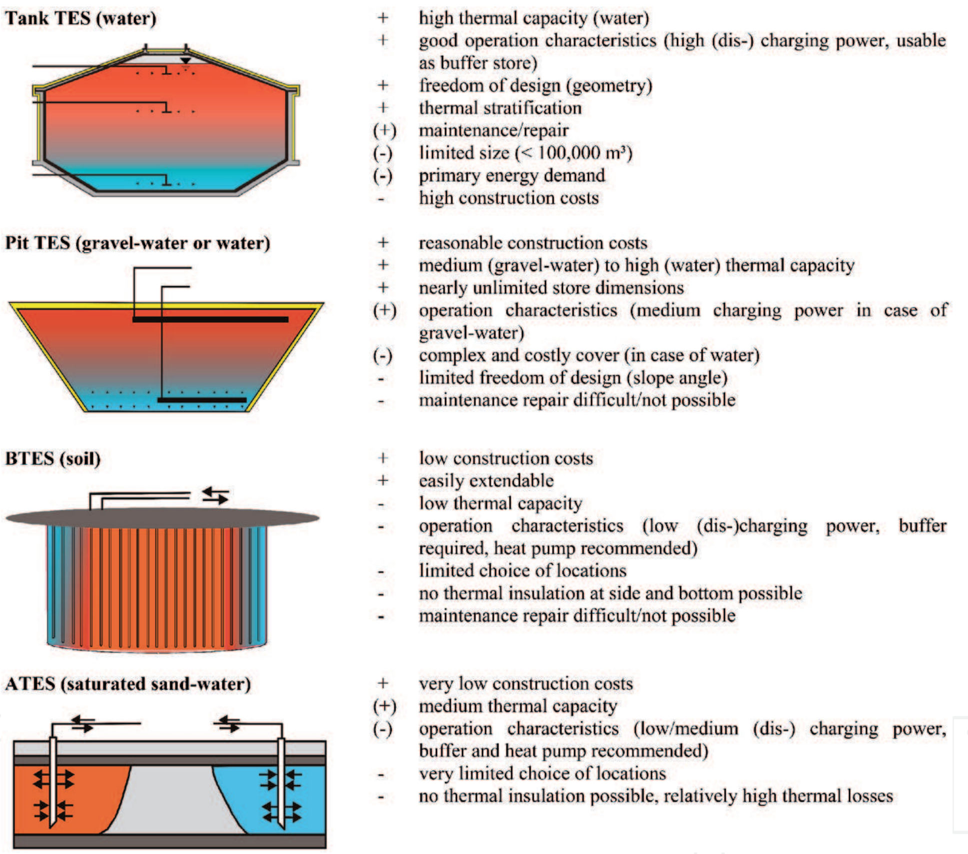

Figure 8.
Seasonal thermal energy storage concepts [31].

aspects of cost-effective largescale seasonal thermal energy storage for LTDH systems have been studied by Ochs et al. as part of the gigaTES[4] initiative [36]. However, the planning and development of seasonal thermal storage require a comprehensive study to identify the project cost.

2.2 Geothermal

Geothermal energy is a reliable and secure renewable energy source. A DH supply temperature below 60°C makes geothermal plants more advantageous to

[4] https://www.gigates.at/

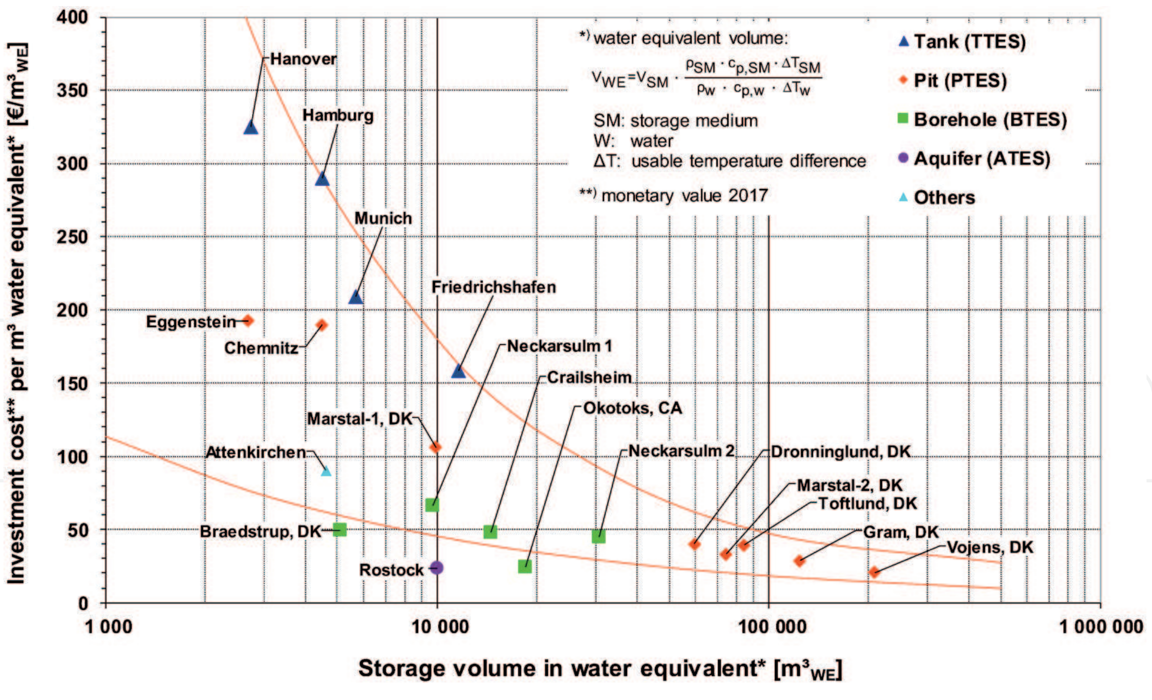

Figure 9.
*Specific investment cost of seasonal thermal energy storage [35]. ** including all necessary costs except the design and connecting pipes costs.*

satisfy the baseload in comparison with solar systems. Geothermal energy can be found independent of locations to fulfill space heating demands directly. One example of LTDH based on geothermal energy is Østre Hageby in Stavanger, Norway, where a low-temperature network with boreholes provides heating to 66 dwellings [37]. The project was completed in 2016 and reduced 61% of energy consumption for space heating and DHW (**Figure 10**).[5]

As a rule of thumb, shallow wells with temperatures between 40–150°C are suitable for hot water DH systems. In contrast, higher temperatures (deep wells) are ideal for electricity generation. The geothermal systems are capital intensive. Drilling can account for up to 50% of the total costs of a geothermal project. It has been shown that lowering the DH supply temperature reduces both the capital and operating costs of geothermal DH systems [38]. The geothermal DH system is a better option than individual geothermal heat pumps. In a comparative study in South Korea, the primary energy use of GSHP was reported higher than district heating systems [11]. Thorsteinsson and Tester have discussed the barriers of large GSHP and provided ten recommendations to overcome the challenges of geothermal district heating system development in the United States [39]. Green Energy Association has compared the DH system and individual heat pump based on the Danish data [40]. The report concludes that a new district heating system's annual operating costs are much smaller than the individual heat pump. Some case studies have been gathered in Pellegrini and Bianchini's literature review [41]. In the light of growing interest towards GSHPs, two concepts of shared GSHPs and centralized heat pumps are discussed here.

The basic principle of a GSHP is presented in **Figure 11**. Heat can be extracted from the ground at a relatively low temperature. The heated fluid is compressed to a higher pressure by a compressor. From there, a second heat exchanger or condenser transfers the heat to the home, via either warm air or circulating water.

One of the essential characteristics of GSHP is that the efficiency of the unit and the energy required to operate are directly related to the temperatures between

[5] https://www.arkitektur.no/ostre-hageby

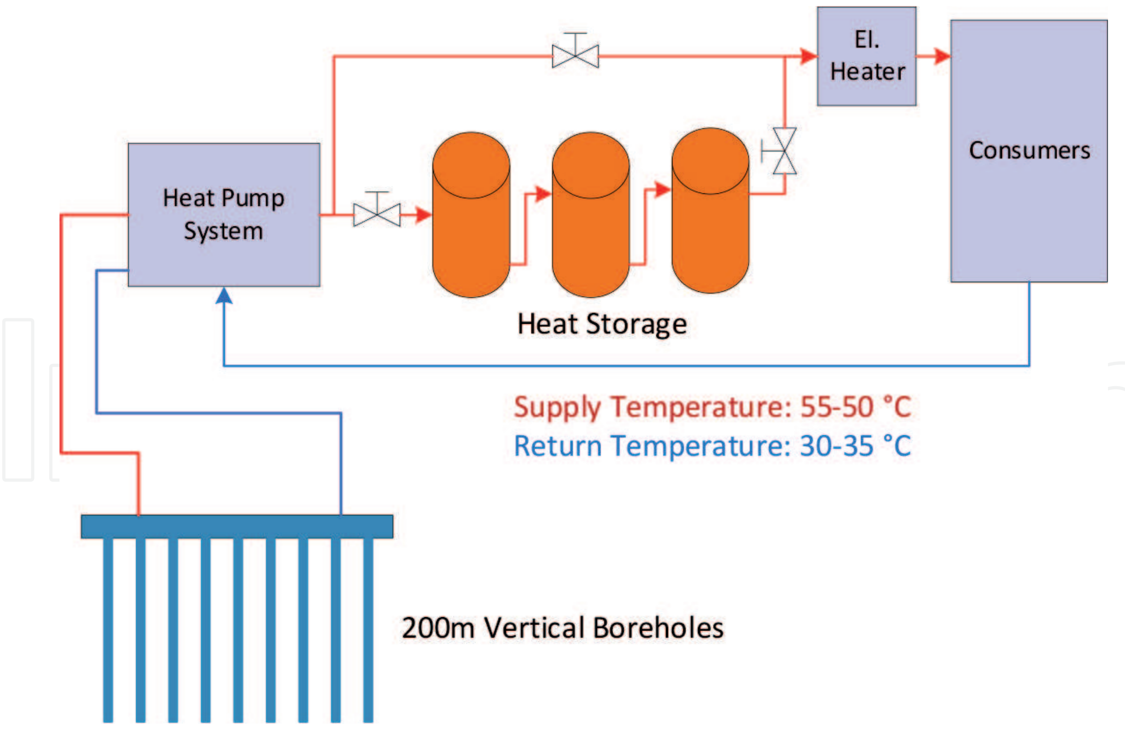

Figure 10.
Simple sketch of the Østre Hageby district heating system.

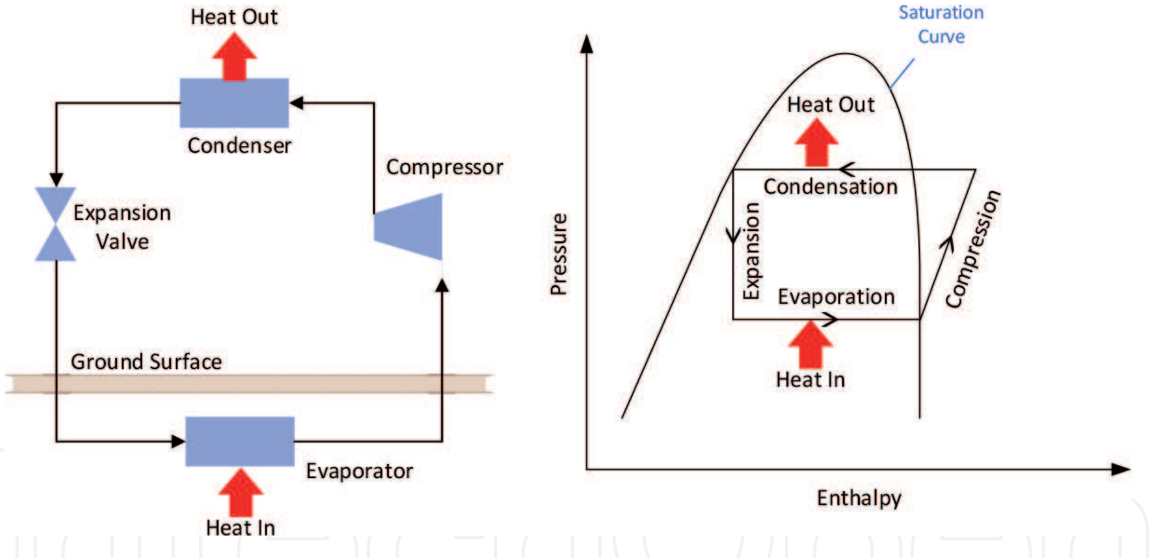

Figure 11.
Process diagram of GSHP.

which it operates. The temperature difference where the heat is absorbed (the "source") and delivered (the "sink") is called the "lift". Larger lift means greater input power to the heat pump. The heating performance of a heat pump is defined by Coefficient of Performance (COP). The COP is the heating produced divided by the energy equivalent of the electrical input resulting in a dimensionless value. The larger the COP value, the less electricity required to operate. The heat transfer between the GSHP and its surrounding soil is affected by a number of factors such as working fluid thermophysical properties and its conditions, soil thermal properties, soil moisture content, and groundwater velocity and properties.

The GSHP has excellent potential to be one of the primary energy sources in the near future. The ground energy can be tapped in a number of different ways and can be used to produce hot water as well as electricity. It has a broad spatial distribution in all countries concerning the low enthalpy resources available. Geothermal

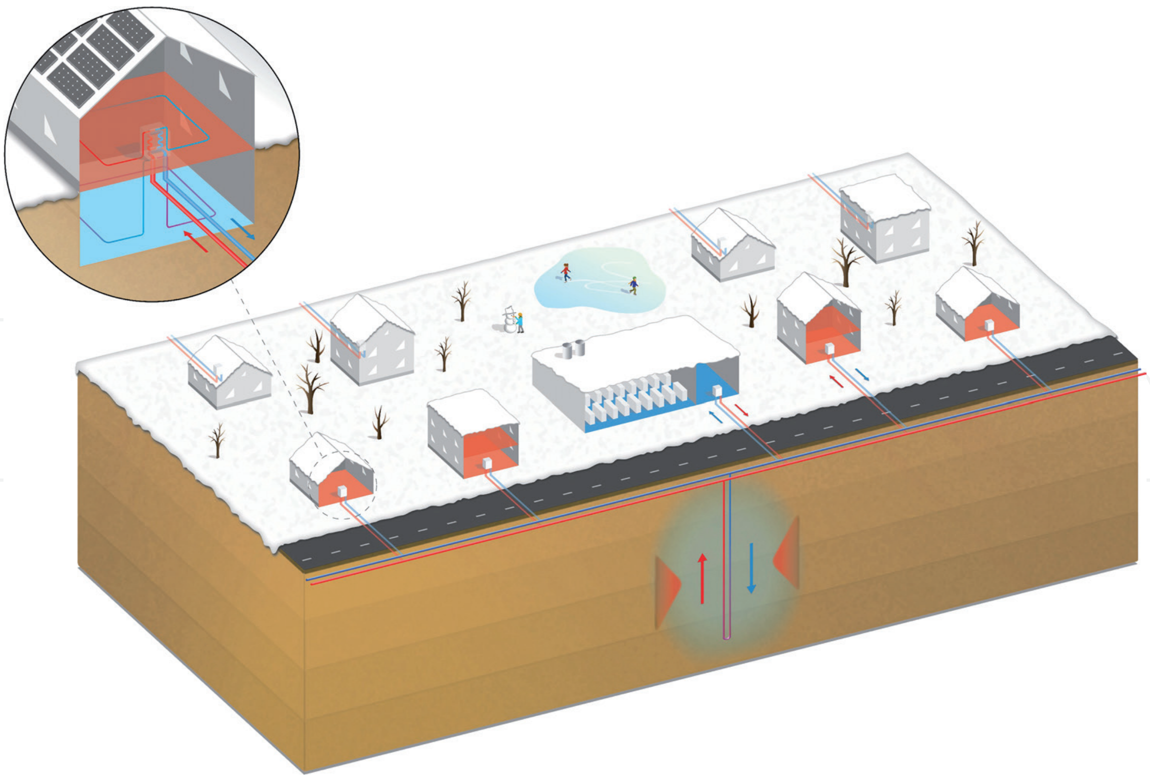

Figure 12.
Illustration of decentralized LTDH based on GSHP in a rural area of Denmark.

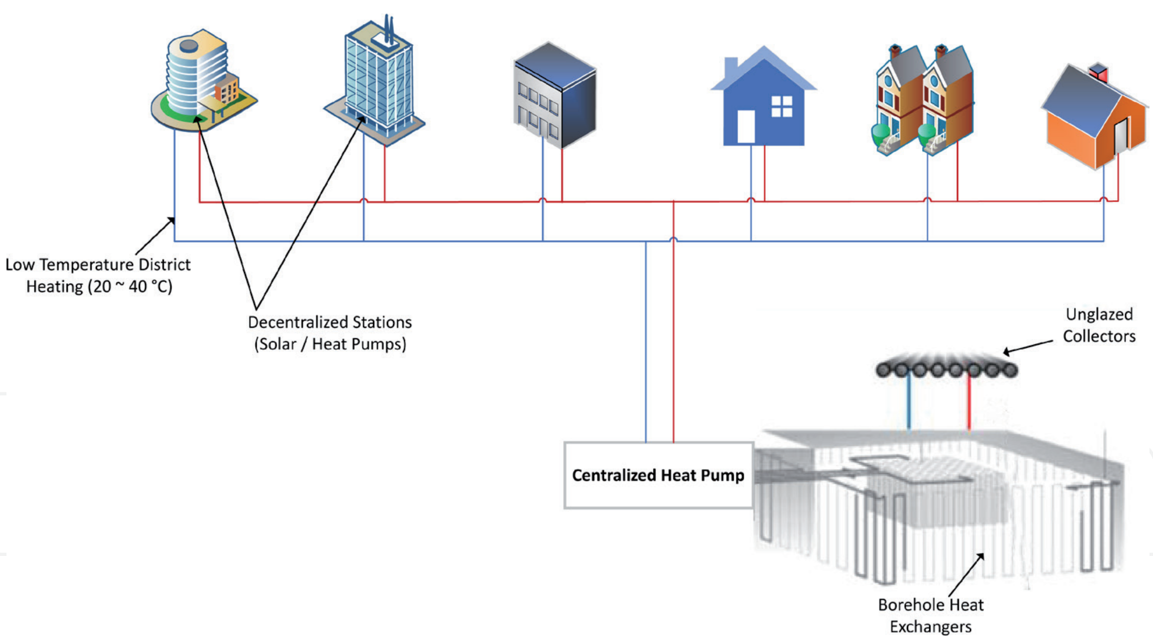

Figure 13.
District heating system of City of Kassel, Germany [46].

energy is a renewable resource that does not rely on specific factors such as the wind or the sun.

A new LTDH concept based on the use of individually adjustable and collectively managed GSHPs, connected to a low temperature non-insulated thermal distribution network has been implemented recently. This concept in the UK is called "Shared Ground Loop[6]," and the related regulations are well established [42]. In Denmark, it is called "Termonet" and is recommended mostly for rural areas. Three

[6] https://www.icax.co.uk/Shared_Ground_Loop.html

Termonet systems have been commissioned in Denmark during 2017 and 2018, with borehole heat exchangers [43] (**Figure 12**).[7]

The connected group of GSHP is based on the following ideas:

1. The aggregated heat demand can be sourced from vertical boreholes [44]

2. The investment costs reduce on the basis that a single larger ground loop will not cost as much as two separate GSHPs

3. Optimization of the heat pump (i.e., operational sequencing) will leads to more energy savings [45] and minimize the boreholes depletion.

4. Seasonal storage can be added to the system to cover both heating and cooling demands and also the distribution network can benefit from solar or other available heat sources

5. The system planning is more flexible and scalable than the centralized approach[8]

The other concept is a central shallow geothermal plant. Shallow geothermal plants have less than 400-meter deep boreholes. Since the extracted temperature can have a wide temperature range, it may require to be raised with a heat pump. **Figure 13** depicted the LTDH system of a new community with 131 low energy residential houses on a land area of 115,000 m^2, located in Kassel, Germany. The system includes a centralized GSHP with an LTDH network. Since the buildings require a higher temperature than what was provided with LTDH, especially for DHW, they were equipped with heat pumps. Different aspects of using heat pumps to balance the temperature in a district heating system have been discussed in the IEA Annex 47 project [47]. In another project (i.e., RELaTED), it has been shown that ground source heat pumps fit well with the LTDH concept [48]. However, further research is yet to come in order to fully understand all aspects of shallow geothermal energy [49].

3. Distribution network

The distribution network's role is the transmission of heat generated in centralized or distributed locations through a system of pipes for residential and commercial heating requirements. The DH heat supply must provide sufficient energy at the appropriate temperature and pressure to meet end-user demands. In LTDH planning, the system design starts with the identification of demands (**Figure 14**). The demand can be calculated on a case by case basis or estimated for a group of buildings. Several tools for heat mapping are developed in order to facilitate DH planning such as:

1. PlanHeat: http://planheat.eu/

2. THERMOS: http://www.thermos-project.eu/home

3. HotMaps: http://www.hotmaps-project.eu

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7 https://termonet.dk/

8 https://www.kensaheatpumps.com/shoebox-ground-source-heat-pump/

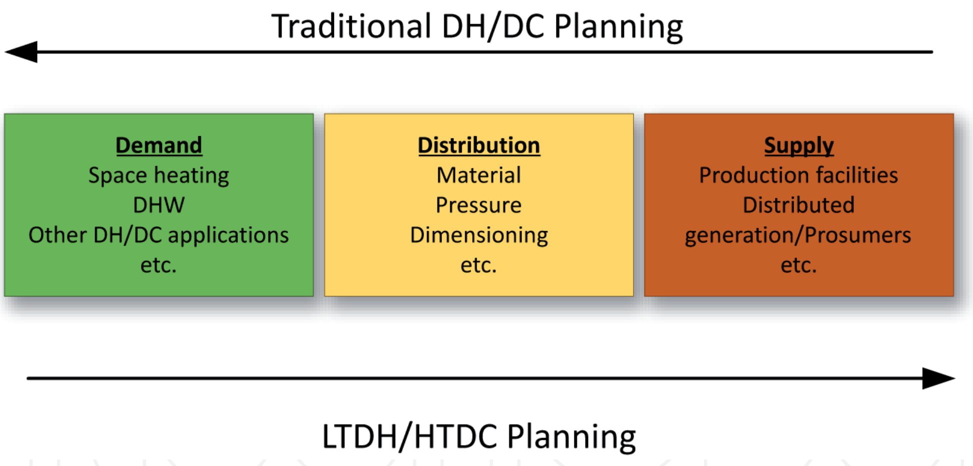

Figure 14.
Basic principles of traditional DH and LTDH planning [50].

The heating capacity of a DH network can be defined by the following three parameters, which are all related to each other.

- Spatial heat density (mean energy demand per hectare, MWh/ha),
- Specific heat density (heat demand per unit floor area in a building, kWh/m^2),
- Linear heat density (energy demand per unit length of heat network pipe, MWh/m)

After determination of heating demand, four factors influence the optimum design of an LTDH network:

1. Pipe length
2. Pipe diameter
3. Pipe insulation
4. Topography and controlling strategies of the network

Several pipe types are available, and the selection of them depends mainly on operating conditions and cost. The different kinds of pipes are ranging from rigid steel pipes to flexible plastic pipes manufacture with pre-insulated bonded. The pre-insulated flexible single or twin pipes are the standard choices for LTDH. A twin pipe integrates both the supply and return lines within one casing. Depending on the insulation thickness, both single and twin pipes are categorized in series 1, 2, or 3. The two types of single and twin pre-insulated pipes are shown in **Figure 15**.

The required pipe length is calculated by the linear length between all buildings within a hectare. Each pipe section must accommodate the peak heat loads.

The pipe diameter defines by heat density and must be carefully selected. The project capital cost and network heat loss are directly related to pipe size. In order to determine an optimum pipe diameter, different techniques have been proposed in recent publications [52–56]. Increasing the pipe size, improve the linear heat density of the DH system and, on the other hand, increases the project cost.

Linear demand density is calculated from the flow velocity and network temperature. Different guidelines recommend different thresholds for the design velocity. The impact of different design guidelines on the DH network cost has been evaluated by Best et al. [57]. They compared the guidelines of Sweden, Germany, and Austria and concluded that allowing high specific pressure drops of ≥300 Pa/m at maximum heat load leads to transportation pipe investment savings of 6–8%. An increase in the pipe diameter without additional insulation thickness increases the

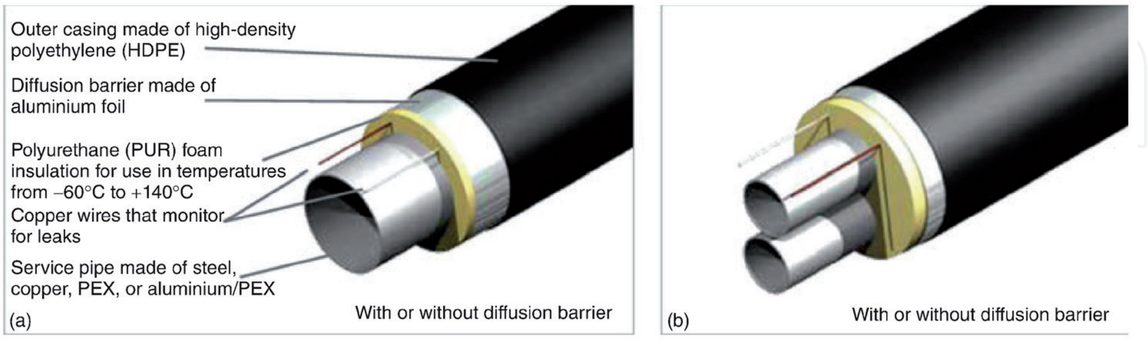

Figure 15.
Pre-insulated district heating pipe (a) single (b) twin [51].

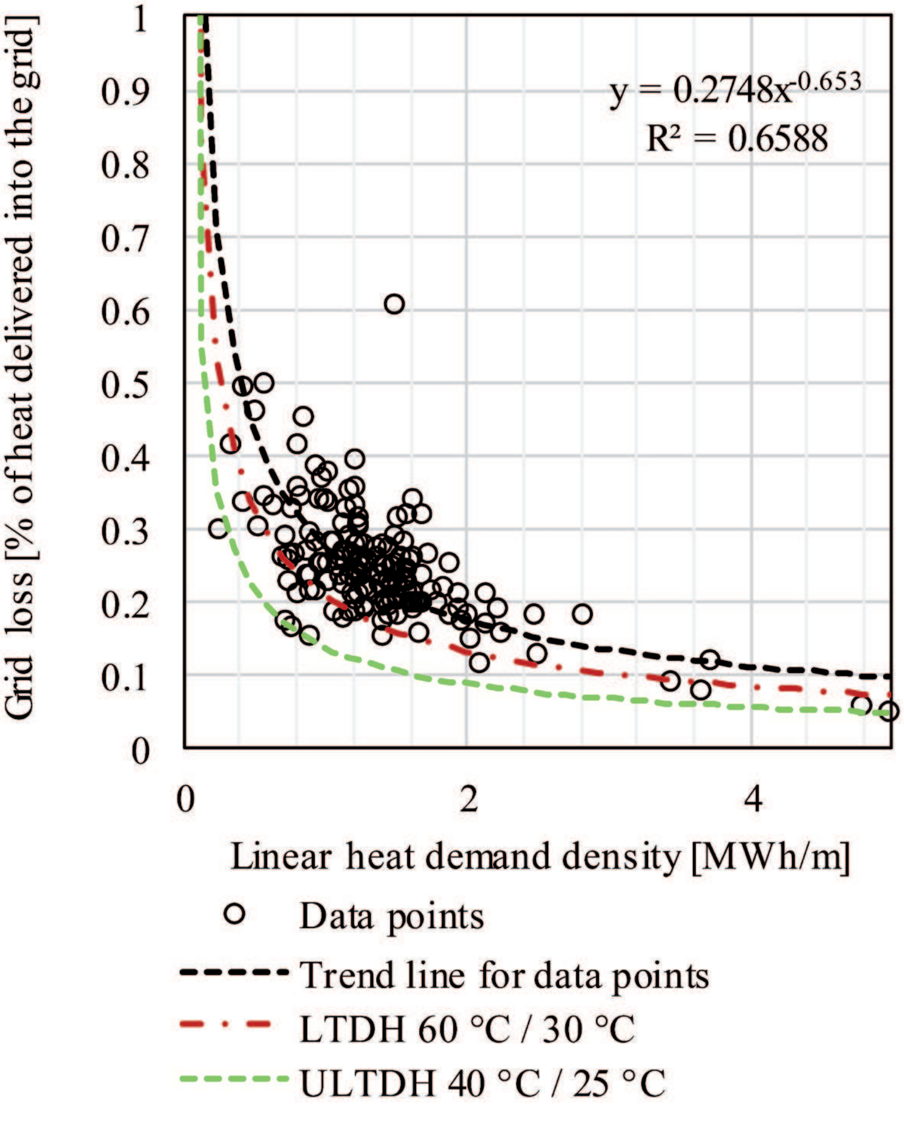

Figure 16.
Heat loss data from the existing DH networks in Denmark [58].

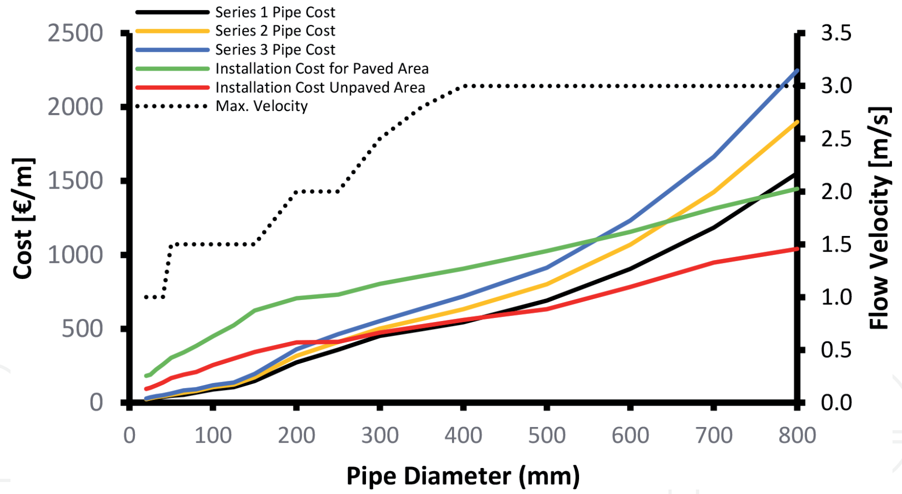

Figure 17.
Prices and maximum fluid velocity of network pipes.

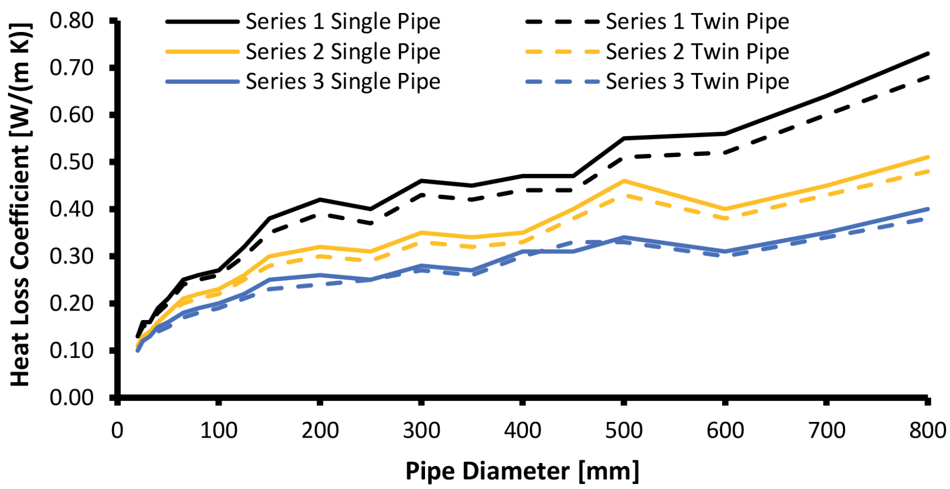

Figure 18.
Typical values of heat loss coefficients and external diameters of pre-insulated pipes.

lateral heat loss. However, this heat loss increase is minimal when compared with the heat density increase. **Figure 16** shows the magnitude of heat loss versus linear heat density.

As part of the effort to expand the LTDH networks, a research project under European Commissions, Horizon 2020, provided a useful pre-design support tool. In this project, which is called FLEXYNET[9], an Excel tool has been developed to carry out preliminary feasibility studies on the implementation of LTDH. The following cost data has been selected from this publicly available tool [59] (**Figures 17** and **18**).

The efficient operation of DH is based on complicated interactions of different heat sources with different consumers. Appropriate control of such a complex system is another challenge of LTDH systems. The control logic is a combination of head/pressure control, temperature control, and distribution optimization. Inadequate control of pressure in the DH network would lead to more water flow through the consumers close to the DH pumps and insufficient water flow through the consumers located far away. Since the supply temperature of LTDH is low, a small unpredicted variation in the demand will impact the system operation and

[9] Fifth generation, Low temperature, high EXergY district heating and cooling NETworkS: http://www.flexynets.eu/

efficiency. Some DH network design approaches are recommended to improve system flexibility. One of these solutions is the ring network [60]. Unlike the traditional designs, ring topology equalizes the pressure differences between the supply and return pipes. The rink network reduces the risk of pressure spike in case of malfunctioning of any control valves.

Further review of different controlling strategies has been provided by Vandermeulen et al. [61]. One of the recent efforts to improve the DH controls is the STORM initiative. In this project, a new control algorithm has been developed and successfully applied in two demo sites [62, 63].

4. Summary

This article described the state of the art of several existing LTDH systems. The advantages of LTDH networks over the traditional district heating networks have been discussed. Reviewed cases and studies intensified the energy efficiency potential of LTDH. This system provides a unique opportunity to integrate renewable heat sources such as geothermal and solar as much as possible. The capital costs of LTDH is generally less than the high-temperature DH. In a very low-temperature district heating concept, heat pumps are required mainly for domestic hot water at the end-users. Since the LTDH technology is relatively new, the regulations, including policies and incentives and design standards, are not well established. Further investigations are needed in order to identify the design criteria and develop regulations, including the transition from the exiting high-temperature DH to LTDH. The behavior of the LTDH under different operating conditions and various design configurations should define by holistic models that are available yet. The LTDH system has the potential to receive full market attention as the technology evolves.

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