Interreg
North-West Europe
HeatNet NWE
European Regional Development Fund

Guide to Integrating 4DHC with Energy Efficiency Retrofitting

Researched by	Checked by	Reviewed by	First Draft	Final Draft
Conall Mahon Patrick Harney	Donna Gartland	Benoit Hofer Odile Lefrère Catherine Fitzgerald	August 2018	October 2018

Author(s): Donna Gartland, Codema
Email: donna.gartland@codema.ie
Phone: +353-1-7079818
Address: The Loft, 2-4 Crown Alley, Temple Bar, Dublin

Deliverable: WP.T3 D1.2 Guide to Integrating 4DHC with Energy Efficiency Retrofitting

Date: October 2018

About HeatNet NWE

This document has been developed as part of the HeatNet NWE project, which is part-funded through the Interreg NWE programme and aims to increase the uptake of 4DHC networks across North-West Europe. As part of this project, the partners are developing the HeatNet Model, which will help the public sector to begin implementing 4DHC networks, and the Transition Roadmaps, which will outline the partners' experience in developing six district heating pilots across North-West Europe. The HeatNet Guide to Financing is also currently being developed and will give a broad overview of the various sources available to finance district heating schemes.

For further information on these reports and on the HeatNet NWE project, please visit www.nweurope.eu/heatnet.

Table of Contents

Introduction

This section of the HeatNet Model is a tool aimed at helping stakeholders across NWE developing district heating and cooling (DHC) projects to overcome barriers to implementing 4th Generation DHC (4GDHC) solutions in existing buildings which are undergoing retrofitting. This guide outlines the key advantages and disadvantages of connecting buildings to 4DHC rather than other individual heating solutions, and a cost comparison of these options, in order for the stakeholder to understand why they should consider a DHC connection when retrofitting a building.

The guide includes information on connection of energy efficient buildings to 4DHC, both from perspective of the DH provider and the building owner. This includes details of identifying and connecting 4GDHC developments, the thermal storage options available and the internal heat emitters required. The guide shows how buildings having high-energy efficiency are suitable for 4GDHC and how they can connect to existing higher temperature DH systems, and also how some existing buildings may not need much retrofitting to allow 4GDHC supply.

The guide also outlines issues with low temperature supply like legionella risks, and how to optimise 4GDHC connections to ensure best efficiencies are achieved. The support schemes for integrating 4gDHC connections and energy efficiency upgrades in each of the partner countries in north-west Europe are summarised.

This task has been led by Codema, working with Dublin based academic researchers, with valuable input from the HeatNet pilot partners.

4DHC Vs Individual Heating Solutions

Definitions

4GDH

District heating can be described as a system in which heat is produced centrally by one or more energy sources and then transported through a network of pipes to the final user [1]. District heating networks can connect the buildings of a neighbourhood, town centre or entire city. District heating has existed since the 1880s and there have been four generations of the technology to date. 4GDH is the latest version of district heating network [1]. 4GDH operates at lower temperatures than previous generations, typically 50°C supply and 25-30°C return temperatures. Lower operating temperatures decrease grid losses and enables low grade sources, such as waste heat from industry, to be fed into networks. 4GDH also integrates renewable heat sources such as solar and geothermal heat.

The 4GDH concept refers not only to temperature of the network but to the overall optimisation of the system through better network design. Examples of better network design include the use thermal storage to reduce peak network flow and hence reduce pipe sizes and heat loss. Another example is the use of twin pipes. These encase the supply and return pipes within a single insulated casing which reduces distribution losses. Furthermore, 4GDH utilises smart technology which enables it to be an integrated part of smart energy systems alongside smart electricity and gas grids [2]. Figure 1 below is a simple schematic of a 4GDH network.

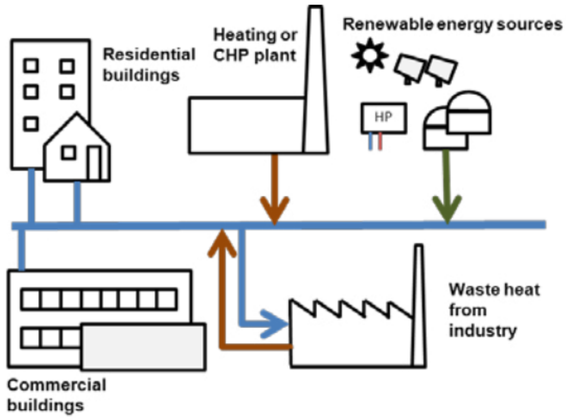

Figure 1: A simple schematic of a 4GDH network [3]

4GDC

District cooling distributes water, cooled to temperatures between 6 and 7°C, to customers through a network of underground pipes [1]. In doing so it provides space heating or cooling to the end user.

The chilled water is mainly obtained from:

- Absorption chillers using a heat source (e.g. waste heat, solar energy)
- Compression chillers powered by electricity
- Free cooling, exploiting freely available cold water (e.g. rivers)

District cooling networks are often installed alongside district heating networks to take advantage of the available heat to generate cold water using absorption chillers, and vice-versa, the heating network can take advantage of the waste heat from chillers. Like district heating, district cooling has also experienced three generations of technology. A future 4GDC system can be defined as a network that utilises smart technology and thermal storage to be interactive with electricity, district heating, and gas grids [2]. Figure 2 below illustrates the sustainable energy technologies that 4th generation district cooling systems (DCS) can be integrated with.

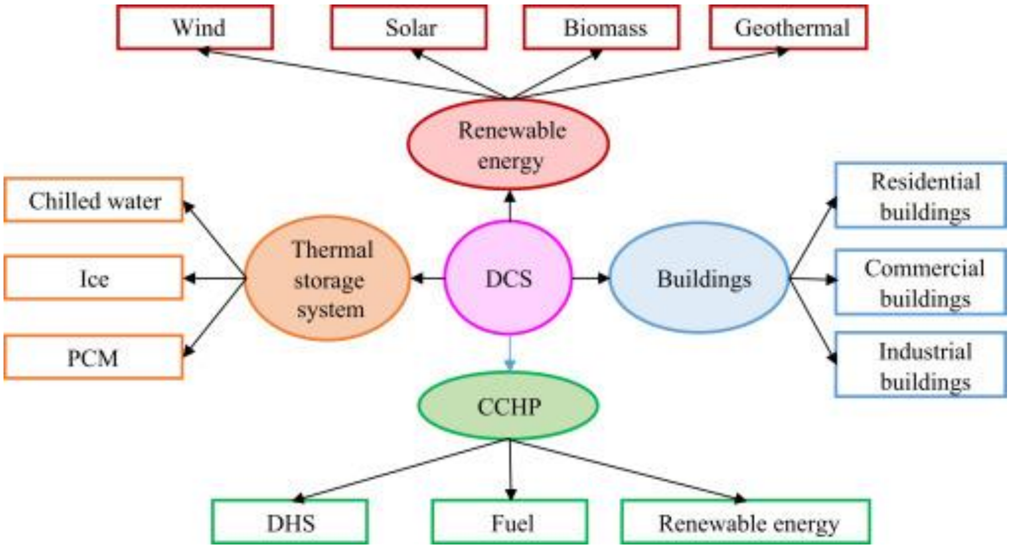

Figure 2: Integration of a district cooling network with different technology and buildings. PCM refers to phase change materials. These are high density materials with a high latent heat during phase change and can be used for cold thermal storage e.g. inorganic salt hydrates [4].

CCHP refers to Combined Cooling Heating and Power systems. These systems can provide cooling, heating and power simultaneously (also known as tri-generation). For DCS integrated with CCHP, thermal driven chillers, powered by low grade heat, are typically applied to generate cooling [4].

Traditional Heating System

Traditional heating systems are individual (decentralised) heating systems, typically powered by fossil fuels. These systems provide space heating and/or domestic HW to the building they service. Examples of traditional heating systems include [1]:

- Condensing and non-condensing boilers fuelled by gas, oil, and coal
- Electric heating systems fuelled by the grid
- Stoves fuelled by coal, gas, or oil
- Furnaces fuelled by coal or waste

Decentralised Renewable Heating Systems

Decentralised renewable heating systems, harness renewable energy sources to provide space heating and/or domestic HW to the building they service. Renewable energy sources are energy sources that replenish (or renew) themselves naturally. Examples of renewable heating systems include [5].

- Solar thermal
- Biomass boilers

- Biomass stoves
- Biomass furnaces
- Geothermal
- High Coefficient of Performance heat pumps

High Coefficient of Performance heat pumps use renewable energy from their surroundings (ambient air, water, or ground) as well as a high-grade energy source, usually electricity. Most heat pumps apply a series of vapour compression cycles, driven by an electrical motor to provide heating or cooling. In doing so, they can achieve point-of-use efficiencies greater than 100%. This means that they provide more useful thermal energy than the electricity input. The three most common types of heat pump system are [5, 6]:

- Air Source
- Ground Source
- Water Source

Advantages and Disadvantages

The advantages and disadvantages of traditional heating systems and 4GDHC systems for both customers and suppliers are outlined in the table below. The district heating section highlights the benefits and problems associated with district heating in general while the 4GDH sections relates solely to the 4th generation of district heating systems. Benefits shared by both 4GDH and district heating in general will appear solely in the district heating section.

Table 1: Advantages and Disadvantages of different heating systems

System	Advantages	Disadvantages
District heating & cooling	**Cost** - District heating and cooling along with energy conservation set out in the heatmap Europe studies can provide a least cost energy efficient solution for Europe while reaching the EU decarbonisation target of reduction of 80% of 1990 levels by 2050[7] - Per unit price is usually fixed for a period time so greater energy and financial security - Investment & Maintenance costs reduced per person to scales of economy - Highly efficient CHP (Combined Heat and Power) plants can get priority access to the grid for their electricity generation	**Cost** - Retrofitting building from electric heating system to a DHC system can be costly **Technical** - Increase risk of legionella growth - Lack of awareness - Can be difficulties finding suitable sites **Environment** - Equipment may cause noise - Water storage tank can be an eyesore - Disruption due to construction of system

	Environment - Better air quality - Less GHG emissions (Figure 3) **Social** - Local Job Opportunities (Helsingborg, Sweden DH increases local purchasing power by €20 million per year [8]) & (Heating plan Denmark 2010 shows that the implementation of a district heating and individual heat pump scenario over a period of 10 years will create between 7 – 8,000 jobs [9] - Potential to decrease fuel poverty (Table 2) **Technical** - Decreased carbon monoxide risks - Heat supply on demand – no run -up times	
4GDH	**Cost** - Ability to harness low temperature sources which weren't previously useful (Waste heat & renewables) - More sources of heat increase competition so reduce prices - Potential to introduce smart metering* to deal with payment with customer integration to allow selling of heat from renewables back into the grid - Companies may be able to sell their waste heat if the market develops **Environmental** - The use of waste heat which has no attached carbon burden offsets the use of fossil fuels or biomass and their related GHG emissions **Social** - Increased energy security as local heat sources utilised which is important in European countries (Table 2) **Technical** - Lower temperature means it is possible to use flexible plastic pipes lowering capital costs [2]	**Cost** - Due to the lower temperature of water supply energy efficient must be greater which increases capital costs. **Technical** - Possible need for heat pumps if temperature is below what is required. - Areas of large waste heat supply will usually be separate from areas of domestic heat demand as they will be large industrial factories **Environmental** - Disruption due to construction

	- Reduces difference between supply and demand temperature so increasing the efficiency of the system - Real time monitoring and demand estimation using weather forecasts can ensure peak demand is reached will ensuring heat losses are minimised	
Traditional Heating Systems	**Cost** - There has been large investment in gas pipelines throughout Europe making governments more reluctant to invest in other heating systems **Technical** - No adaptations needed as already in place in majority of buildings (fossil fuel sources make up 66% of useful heat demand while district heating represents 12%) [10] - Greater Technological maturity and associated lower capital costs - More qualified technicians for traditional systems	**Cost** - Market volatility due to fossil fuel supply being controlled by a few countries. (Introduction of 3DH was initiated by the 1970's Oil Crisis) **Environmental** - GHG and particulate emissions **Social** - Reliant on fossil fuels - Fossil Fuels are a finite resource - Most European countries are net importers of fossil fuels, so these systems only continued to decrease energy security **Technical** - Less efficient systems leading to heat losses - Greater carbon monoxide risks
Renewable energy systems	**Cost** - Per unit price is usually fixed for a period time so greater energy and financial security - Ability to integrate with grid to sell additional energy. **Environmental** - Better air quality - Less GHG emissions **Social** - Potential energy independence - Job opportunity - Greater citizen control on energy **Technical** - Decreased carbon monoxide risks	**Cost** - Large initial investment with the burden on the individual **Technical** - Retrofitting building may be expensive - Lack of technological maturity - Problems with meeting base load (Solar doesn't match with peak demands). - Intermittent supply **Environmental** - Possible disruption due to construction - Some technologies can have an impact on the local environment e.g. wind farms can impact migratory birds [11]

*A smart meter digitally sends meter reading to your energy provider for more accurate energy bills. It can give the customer greater insight their energy usage allowing them to reduce their bills.

Table 2 represents the EU's dependency on energy imports and highlights a social problem of some of its residents being unable to warm their houses adequately. This is important in the context of district heating and especially 4GDH as it can integrate many local sources of heat like waste industrial heat and low temperature renewables reducing the need for energy imports. District heating can also solve social problems like inability to heat a home as residents would have a constant source of heat which could be subsidised compared to subsidy for oil or coal heat systems which rely on the user being able to afford and access the fuel themselves in advance.

Table 2: Table represents energy dependency and fuel poverty in NW Europe in comparison to EU Average

Countries	Net primary energy import [12] (tonnes oil eq./capita)	% pop. Inability to keep home adequately warm [13]
Belgium	1.8	4.8
France	1.8	5.8
Holland	2.8	5
Ireland	2.7	2.6
UK	1.1	6.1
EU Average	1.8	8.7

Figure 3 is a comparison of the associated CO2 of examples of European district heating systems compared to averages of other common heating systems in Europe. The CO2 emissions of effective district heating systems are at least half that of other common heating systems in Europe. PRF measures the losses between energy generation and delivery excluding the renewable component of primary energy. In Figure 3 the lower PRF of the district heating systems highlights the greater use of renewable energy compared to other traditional systems.

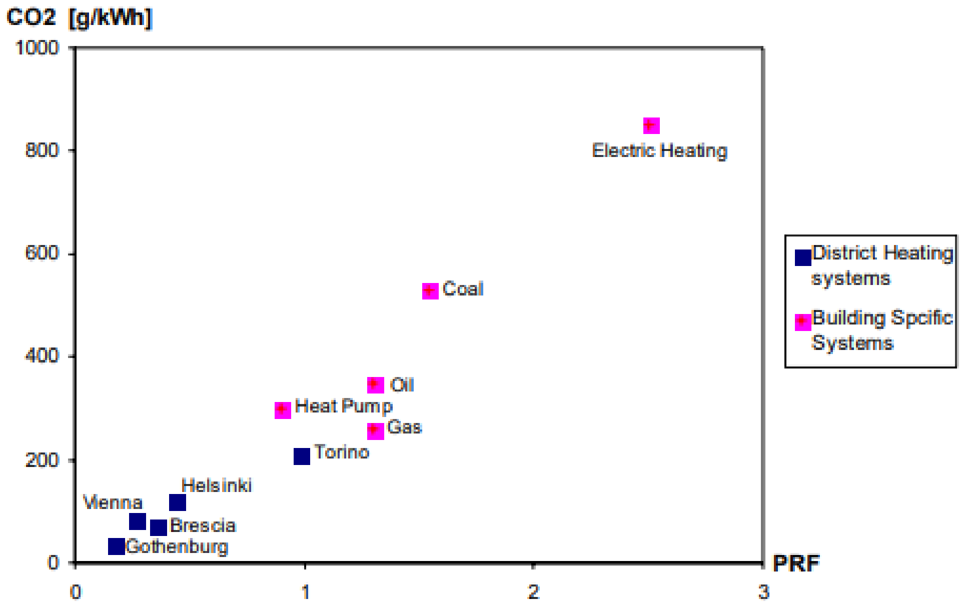

Figure 3: The associated C02 (g/kwh) of examples of European district heating systems compared to averages of other common heating systems

Cost Comparison

In Codema, a techno-economic study for South Dublin DH scheme, Codema has carried out a comparison costs between connection to a future DH and individual systems in place (gas boilers). The area of the study is Tallaght town centre, which is a dense urban area. The table below shows the result of this comparison.

Table 3: Cost comparison of an individual gas boiler system vs a district heating system in the Codema study.

Comparison of Consumer Costs			
Total Consumer-Side System	**Individual**	**DH**	**Difference**
Heat Demand MWh	25,864	25,864	
Investment	1,060,000	742,000	318,000
Annual Fuel/Heat Costs	1,262,434	1,208,000	54,434
Annual O&M	139,667	53,000	86,667
Total Annual Costs	1,402,101	1,261,000	141,101

This study shows that connection to the DH scheme would save the buildings a total of €318,000 on investment (when connecting to the DH instead of investing in new gas boilers) and €141,000 on total annual costs. If we calculate a heat cost from these figures (with an investment over 20 years), the individual system heat cost would be around €56/MWh (Ex.VAT) whereas the DH heat cost would be around €50/MWh (Ex.VAT)[1].

[1] prices as of 2014

Table 4: Cost of heat from different DH schemes for low energy buildings in €/kWh (Source: Gudmundsson, 2013). District heating assumes that construction in inner city as these areas are most likely to have the necessary heat demand density required.

Country	**District Heating**				**Individual Heating**			
	Gas Boiler	***Biomass Boiler***	***CHP Waste***	***Geothermal Plant, Low Temperature***	***Gas Boiler***	***Air source heat pump***	***Electrical Boiler***	***Solar Thermal***
Bulgaria	0.091	0.109	0.066	0.142	0.116	0.161	0.118	0.121
Denmark	0.126	0.109	0.066	0.144	0.173	0.216	0.173	0.129
Ireland	0.099	0.108	0.066	0.146	0.129	0.193	0.216	0.125
Portugal	0.097	0.095	0.066	0.145	0.141	0.188	0.199	0.125
United Kingdom	0.086	0.106	0.066	0.145	0.128	0.187	0.196	0.124

Table 4 is a representation of the data from Gudmundsson, 2013[15]. It shows that when considering the lifetime of the technology that in most cases district heating is much cheaper than individual heating systems. In terms of district heating fuel type, it represents that a heating system that can make use of waste heat will drastically reduce per unit costs. Table 4 also compares renewable sources (geothermal & solar) with other technologies, with geothermal being the most expensive option in terms of district heating. However solar thermal is at least competitive with other individual systems meaning it may be a viable option in areas with too low of a heat density for district heating to be viable.

Another study from COHEAT (UK) [16] shows that 5GDH (4GDHC with smart control) is a cheaper solution than individual gas boilers. COHEAT DH is designed for a group of 24 individual homes and a laundry. The heat cost for a 5GDH is around €108/MWh (Figure 4) whereas the estimated cost with an individual gas boiler system is around €169/MWh. (Note: These figures include financing and capital replacement costs, and are therefore higher than costs outlined previously for Irish system.)

Figure 4 shows the implementation of 5GDH within a smaller scale can be more economically viable that individual or 3GDH. 5GDH can also allow the integration with the grid or with other renewable systems.

Figure 4: Shows a lifecycle analysis for 5G DH system, Individual boiler and a 3G DH system. Price (£/MWh) is represented by the bar chart with the GHG emissions (kgCO2e/MWh) is represented by the green dots

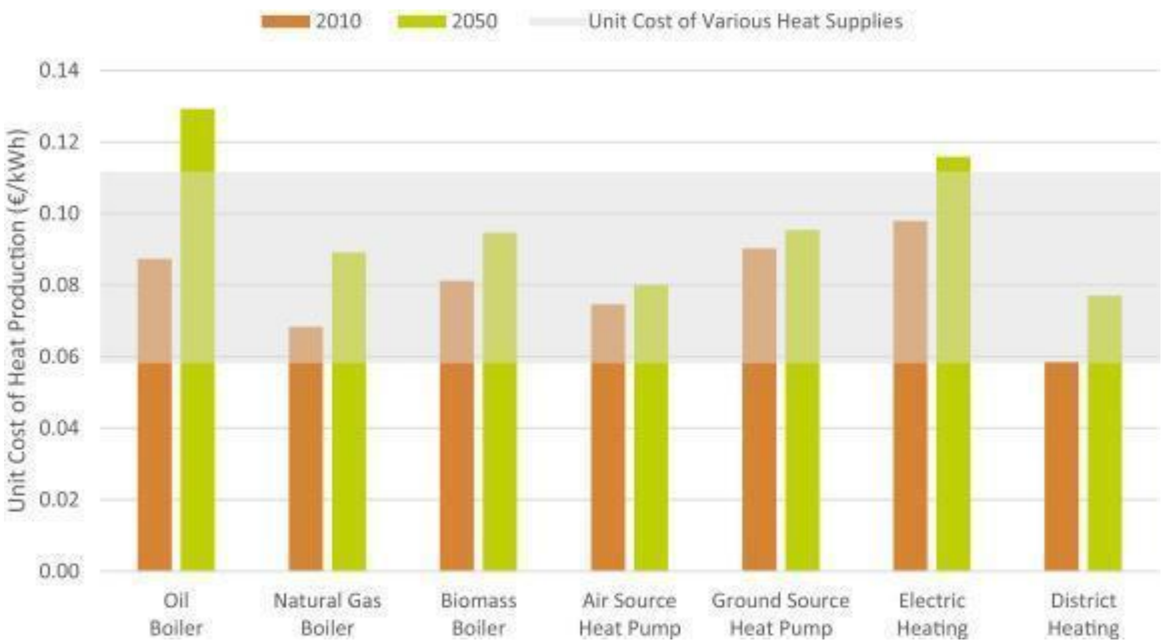

Figure 5: Unit cost of heat production for various heat supply technologies in the years 2010 and 2050 [17]. EU Average and predicted fuel cost are used

A European Heat Roadmap study into saving heat vs supplying heat in found that district heating produces the lowest per unit prices but with predicted price changes air source heat pumps will be a close competitor by 2050 (Figure 5). So, district heating supplemented by heat pumps where it isn't possible to use district heating seems the most viable option.

Chapter 1 References

1. Commission., E., *Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)*, E.C.D.I.-G.F. ENERGY, Editor. 2016.
2. Lund, H., et al., *4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems.* Energy, 2014. **68**: p. 1-11.
3. Schmidt, D., et al., *Low Temperature District Heating for Future Energy Systems.* 15th International Symposium on District Heating and Cooling (Dhc15-2016), 2017. **116**: p. 26-38.
4. Gang, W.J., et al., *District cooling systems: Technology integration, system optimization, challenges and opportunities for applications.* Renewable & Sustainable Energy Reviews, 2016. **53**: p. 253-264.
5. European Commission, *Review of available information Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling.* 2016: Brussels.
6. Ireland., SEAI., *Heat Pump Technology*, in *Best Practice Guide.* 2013: Dublin 2, Ireland.
7. Connolly, D., et al., *Heat Roadmap Europe 2050: 2nd Pre- study for the EU - 27*. 2013, Department of Development and Planning, Aalborg University.
8. Kemira, *District heating cooperation reducing emissions in Helsingborg*. 2014.
9. Dyrelund , A. and H. Lund, *Heat Plan Denmark 2010: a road map for implementing the EU directive on renewable energy*. 2010, HOT/COOL - International Magazine on District Heating and Cooling. p. 11-13.
10. Perrson, U. and S. Werner, *Quantifying the Heating and Cooling Demand in Europe*. 2015, Stratego.
11. Barrios, L. and A. Rodriguez, *Behavioural and environmental correlates of soaring-bird mortality at on-shore turbines*. Vol. 41. 2004. 72-81.
12. Eurostats. *Energy production and imports* 2017 23/05/18].
13. Eurostats. *Inability to keep home adequately warm - EU-SILC survey*. 2016 23/05/18].
14. Cool, E.H., *Guidelines for assessing the efficiency of district heating and district cooling systems*. 2006, Euroheat & Power.
15. Gudmundsson, O., J. Thorsen, and L. Zhang, *Cost Analysis Of District Heating Compared To Its Competing Technologies*. 2013, Energy and Sustainability IV. p. 3 - 13.
16. Coheat, *Coheat 5G Heat Network Demonstration*. 2016, Department of Energy and Climate change UK.
17. Hansen, K., et al., *Heat Roadmap Europe: Identifying the balance between saving heat and supplying heat.* Energy, 2016. **115**: p. 1663-1671.

Connection of Energy Efficient Buildings to 4DHC

This chapter outlines some key elements to consider when connecting energy efficient buildings to 4GDH. Building refurbishments reduce building heat demand and this has a direct impact on DH integration. DH networks which supply low efficiency buildings show a better cost effectiveness than those supplying high efficiency buildings, as heat sales are increased. As building efficiency increases, energy consumption will fall however, integrating energy efficient buildings provides DH optimisations, such as:

- Reducing DH supply temperature and so, reducing heat losses in distribution pipes and operating costs
- Lowering heat load resulting in smaller equipment, smaller pipes, and cheaper investment
- Lowering temperatures enabling the use of low grade waste heat, thus lowering cost of heat.
- Connecting the return supply from high temperature networks to feed energy efficient buildings [1].

These optimisations can make high efficiency buildings connected to 4DHC viable, even when heat density is quite low. There is a balance to be found between heat density and DH optimisation, keeping quality of service and costs in mind. Below is an example how a passive building could be connected to a 4GDH network (*from CELSIUS Toolbox*).

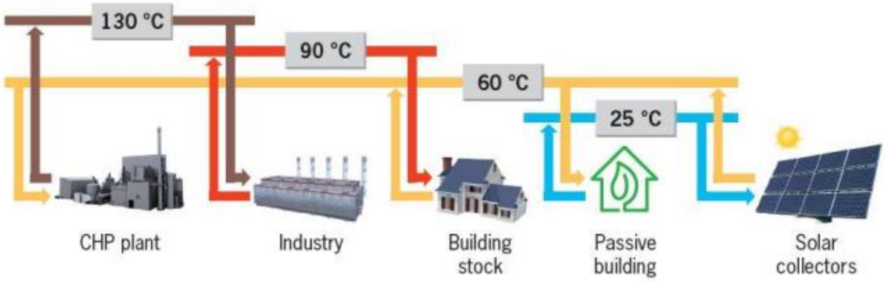

Figure 6: A passive building supplied by the return flow of a 3rd generation district heating network

The role that 4GDH can play in this future low-carbon energy system was examined by Aalborg University in Denmark [2]. This study modelled the economic and technical feasibility of increasing building efficiency in the city of Aarhus, Denmark. The study found that for large energy savings to be achieved, a combination of energy saving retrofits and 4GDH is the cost-effective approach. The costs of adding additional heat saving retrofits is greater than that of supplying district heating after heat savings of 30-50% have been made. This relationship is shown in figure 7 below.

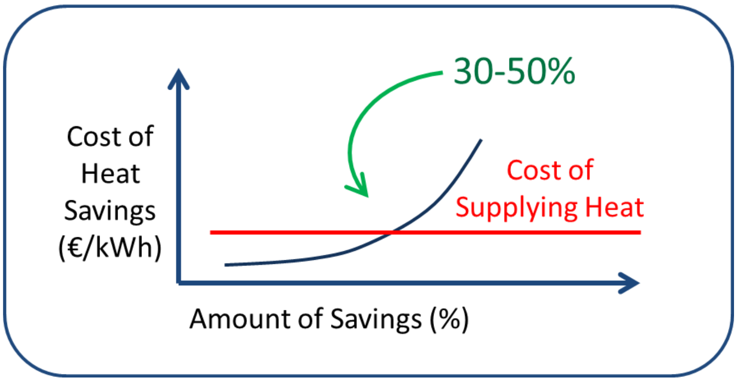

Figure 7: The cost of heat saving as a function of building efficiency achieved

This study suggests that 4GDH must play an important role in reducing building energy demand across Europe. In every situation, the implementation of a 4GDH with energy efficient buildings should focus on feasibility and particularly heat density and optimisation. A feasibility study should be carried out to ensure that the connection of efficient buildings is cost effective. As DH is a local heating solution, every situation is case specific and must to be studied.

This chapter focuses on some key technical points to consider when connecting energy efficient buildings to 4GDH, namely:

- Heat density
- Heat power and load
- Heater technology
- Connection to existing, extended and new 4GDH networks

Each of these elements is discussed and examples are given of situations that can be encountered. A cost comparison of energy efficient buildings vs old buildings connected to 4GDH as also carried out in this chapter.

Heat Density

Heat density is an important factor in determining whether DH may be economically viable in an area. There are two methods of measuring heat density, these are linear heat demand density and spatial heat demand density. Linear heat demand density is defined as the ratio of the annual heat delivered to the consumers (at the interface building/network) and the trench length of the DH network serving that area [3]. It is typically measured in annual MWh/m.

Spatial heat density is a measure of how concentrated heat demands are over a specific land area. It is measured in annual kWh/m² or TJ/km² of heat demand. A high concentration of heat demand results in lower distribution capital costs per unit of energy sold. The following graph (from Heat Roadmap Europe) shows the cost of selling energy, as a function of heat density.

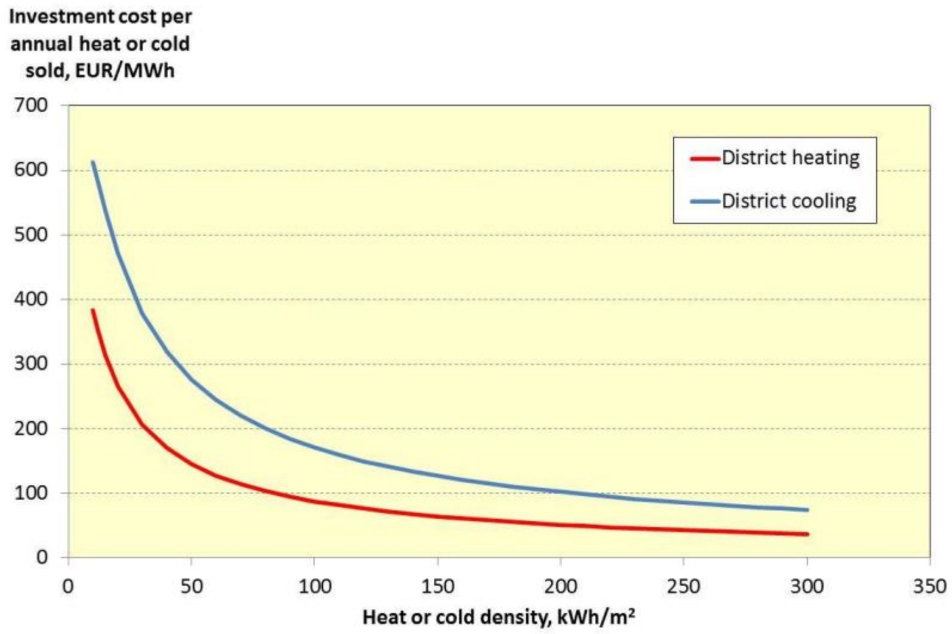

Figure 8: The specific investment cost per heat or cold annually sold as function of the spatial energy demand density for conventional district heating [4]

This graph shows that as heat demand density increases, the investment required per MWh of energy sold decreases logarithmically. This indicates that DH networks are more financially attractive in areas of high heat demand density. In Denmark, areas with heat demand density, above 150 TJ/km² (41.7 kWh/m²), are deemed technically and economically suitable for conventional DH systems [5]. While the above graph relates to conventional district heating, a similar relationship exists between heat demand and cost for LTDH systems. LTDH is however viable at lower heat demand densities than conventional DH.

For areas with very low heat density, the cost effectiveness of a DH should be studied however with the development of 4GDH, networks become viable at lower heat densities. As mentioned in the introduction, it is important to study the feasibility of each DH network separately as local opportunities and design optimisation can make DH viable even at low heat demand densities. The following case studies provide examples of 4GDH being applied to areas of varying heat demand density.

Example: South Dublin County Council (Ireland)

A Spatial Energy Demand Analysis has been conducted by Codema in 2015 for South Dublin City Council to map the energy demand in South Dublin. Areas of potential with a heat density above 150 TJ/km² are identified as areas of priority for LTDH feasibility studies.

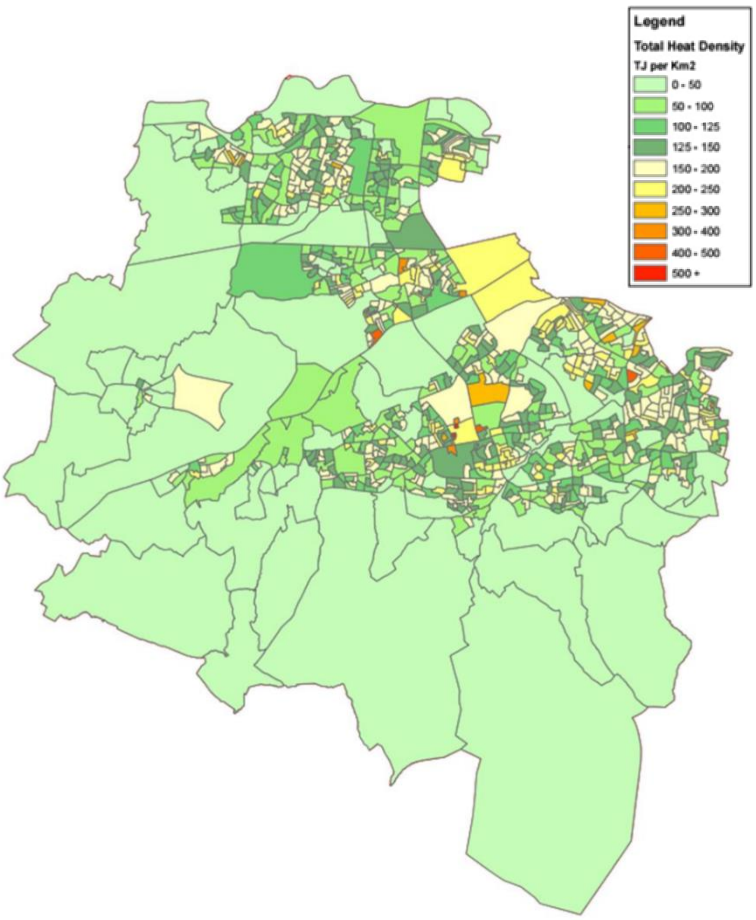

Figure 9. Heat demand density map of South Dublin [5]

In 2015, Codema carried out a techno-economic analysis feasibility study for District Heating in one of the area of priority, Tallaght Town Centre. The heat density of the area is 549 TJ/km^2, well above the traditional Danish threshold. This heat density does not account for other buildings that could possibly connect to the DH later and increase the heat density.

The heat density of the area is equivalent to 150 kWh/m^2, looking at the Heat Roadmap Europe graph in Figure 8, this corresponds to a heat cost of approx. €60/MWh. This seems to be a competitive price for heat but must be compared with local heat price paid by each potential future DH customer in Tallaght Town Centre. The project has been deemed viable by Codema and is currently in the planning phase. This case study demonstrates how spatial heat demand analysis can be used to determine suitable DH network locations.

Example: Lystrup (Denmark)

This demonstration project, funded by the Danish Energy Authority, connects 40 newly built, low energy terraced houses to a LTDH network. The spatial heat demand density of this area is very low at 12.8 kWh/m^2 and the linear heat density is 277.78 kWh/m. The LTDH network was designed to operate at a temperature of 55°C. This project focused on demonstrating the operation and energy demand of DH applied to low energy buildings and that the heat losses in this network could be maintained below 15 – 20% of the total delivered heat [6]. This project also evaluated two designs of LTDH substations.

This LTDH network is an extension of the main municipal DH located in Lystrup. This municipal network is a medium temperature network which operates at supply temperatures up to 80°C during winter months and down to 60°C during summer months. Water flow from the municipal network is mixed with the return flow of the low temperature network using a mixing shunt to create the low temperature network supply. Network measurements taken during 2010 and 2011 are shown in the table below.

Table 1: The measured results of the LTDH network in Lystrup

Year		**2011**	**2012**
Total heat delivered to LTDH network	MWh	273.9	282.6
Heat Demand	MWh	217.4	232
Distribution heat losses	MWh	54.5	50.6
Distribution heat losses	%	19.9	17.9
Heat power, yearly average	kW	31.3	32.3
Supply temperature, DH	°C	67.4	66.2
Supply temperature, LTDH	°C	52.7	52.1
Return temperature, DH	°C	34.1	33.7
Electricity use, pumping station	kWh	2556	-

This demonstration project has been a success. It shows that the SH and DHW requirements of low energy buildings can be met with a DH supply temperature measured at about 52°C on average, with no temperature boost from heat pumps required. This is confirmed by the fact that there were no complaints made from residents about a lack of SH or DHW. The energy efficiency target of the network was also met with the annual heat loss equal to 17% of the total network production. The heat loss of the LTDH is approximately one quarter the heat loss of the nearby medium-temperature network. This case study is also example of how LTDH networks can be integrated into DH existing networks and that LTDH is feasible even in areas of low heat demand.

Example: COHEAT (UK)

COHEAT focused on the delivering LTDH to the typology of dwelling that is the largest part of the UK market. They designed a LTDH for 24 individual homes and a laundry. The linear heat density was very low, at approximately 0.2 MWh/m/yr. [7]. COHEAT believe that a cost-effective solution should be found for this typology of dwelling as they represent the mass market in UK. COHEAT designed what they called a 5GDH solution (4GDH with smart control). The DH system design was quite simple consisting of instantaneous plate heat exchangers for Domestic Hot Water (DHW) and a direct connection for SH supply. Air source heat pumps were also installed at each dwelling for heating purposes.

COHEAT minimised the cost by optimising the design of the DH network by ensuring no network over-sizing and low consumption loads on the district resulting in lower investment costs (heat power plant, pipes etc. They also optimised the running of the DH by implementing smart control that could regulate accurately the heat and hot water demand, reducing excess of heat production and heat losses. The results during a full year (from 01/02/2016 to 01/03/2017) are displayed in the table below.

Table 2: The network results of the COHEAT network between February 2016 and March 2017

Gas boiler efficiency	**92% gross**	(73,064 kWh(th) from 7,138 m³ at 40 MJ per m³)
Heat pump COP	**3.8**	(16,300 kWh(th) from 4,313 kWh(e) including circulator)
Distribution losses	**14.7%**	(85,757 kWh(th) supplied / 74,787 kWh(th) delivered)
Pumping cost	**0.6%**	(425 kWh(e) per 74,787 KWh(th) delivered)

The results show a difference between modelled predictions and measured performance.

- The gas boiler efficiency was lower than expected value of about 95%. This was the case because the boiler was larger than required, the heat load was lower than expected, and, the inlet/outlet temperatures were higher than expected.
- The distribution losses were higher than expected. This could be explained by poor insulation of house entries and, because the boiler had to run at higher temperatures and so higher temperatures were found in the distribution network. As well, some houses were empty.

This project is a demonstration of DH supply to a very low heat density area. It shows that DH can be an option even for small density areas. It also demonstrates that the design and the operation of the DH network must be adjusted to a specific area to make them viable.

Example: Västerås (Sweden)

In a new area of Västerås, 130 low energy houses are connected to a LTDH [8]. This LTDH has a low linear heat density (below 1 MWh/m) and is connected to the existing DH. Despite the low heat demand, the connection of these low energy buildings to the LTDH network was made feasible by:

- Lowering the distribution losses (low temperature implies low heat losses)
- Lowering the network capital investment (lower supply temperatures allowed for plastic piping)
- Increasing the heat demand of each building by connecting white goods to the DH (washing machines, dishwashers)[2].

Heat Density: Key points

District heating is most relevant in urban areas of high heat density however these examples demonstrate the feasibility of 4DHC in areas low density areas where there are low energy buildings. These examples show that 4DHC can be relevant in both urban and suburban areas. LTDH offers significantly fewer distribution losses. This fact coupled with less capital investment costs make 4GDH viable even in suburban areas of low heat demand and to buildings which have had energy efficiency upgrades. 4DHC remains a local opportunity for heating and must deal with local issues and be adjusted in consequence. Although, potential areas can be identified from spatial heat demand analysis, the feasibility of 4GDH networks must be studied locally to identify local opportunities and potential optimisations.

Heating Power and Load

Thermal Load is the amount of energy required to satisfy the SH and DHW demand each building in a network at a point in time. Thermal load is a key element in 4GDH network connection design as it determines the supply pipe and heat exchange unit size required. Large peak loads result in increased capital investments and greater heat loss as networks must be oversized to meet demand at these times. Reducing peak network load results in capital cost savings and more stable renewable energy plant operation. This is also enables the greater utilisation of waste heat and renewable resources which are often of constant supply and can't be scaled up when required [9].

As mentioned previously, reducing heat demand through energy saving retrofits results in smaller peak loads [3]. Energy efficient buildings are therefore suitable to 4GDH connection in the sense that heat demand is more constant than that of traditional buildings. While lower heat demand densities can increase the cost of distribution, 4GDH has been shown to be the cost-effective method of achieving energy savings above 50%, as mentioned in the introduction.

Thermal load in DH networks can be split into two categories. These are physical heat load and social heat load. Physical loads depend on *physical* conditions like temperature or solar radiation. Social heat load depends on the *behaviour* of DH customers such as a demand for hot water in the mornings. Heating loads typically depend on:

- External temperature and weather conditions

[2] White goods that are designed to take warm water feed may not be readily available in every country

- Domestic heating and hot water use patterns
- User requirements (desired internal temperature and occupation of homes) [10]

This chart shows daily heat load variations in the Gothenburg DH network at different times of year.

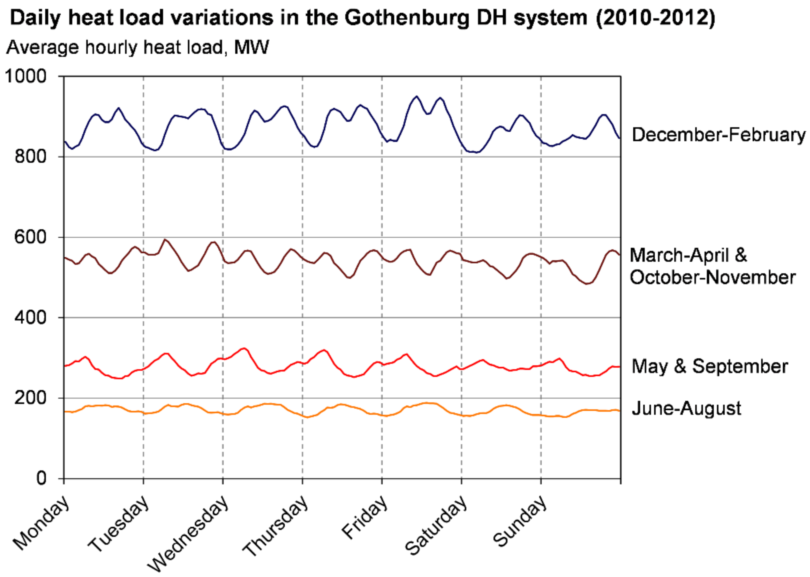

Figure 10. The daily heat load variation of the Gothenburg network at four times throughout the year [11].

As is expected, network loads are much higher in winter months when there are lower temperatures and less solar radiation. There are also two daily peaks, one in the morning and in the afternoon. This is more pronounced in winter months.

There are several cost saving advantages to eliminating peak loads in DH networks such as:

- Less use of expensive peak load power where often expensive fuels are used.
- Less need for peak load power capacity.
- Less need for electricity for district heating network pumping.
- Improved utilisation of industrial excess heat.
- Easier to optimise the operation that leads to higher conversion efficiencies.
- Less need for maintenance because of a smoother operation of the plants [10]

Thermal energy storage is an essential component of 4DHC systems, and when retrofitting buildings to connect to 4DHC, an evaluation of onsite versus offsite hot water storage should be considered. Thermal energy storage can aid in reducing the peak generation of heat by storing heat during hours with lower demand and discharging it during high demand hours. Three types of thermal storage can be used to reduce peak loads:

- Network Storage systems
- Thermal energy storage in buildings
- Seasonal thermal energy storage

Network Storage

This involves the build-up of large volumes of heated water to be stored during times of low demand. This is usually done using large tanks located centrally within networks.

Example: Rotterdam Heat Hub

In Rotterdam DH, the waste to energy power plant is connected to the DH network via 26 km of pipes and a heat hub. The heat hub aims to manage the heat demand and heat production, with buffering, heat balancing, smart ICT and forecasting. A buffer tank, containing 5,000 m^3 of water, is used during peaks to supply the DH, instead of gas boilers. In off-peak times, the buffer tank is filled up with unused hot water from the DH. This thermal storage tank offers several benefits to the operation of the DH network [12].

- Using less fossil fuel during peak load
- Reduce local emissions and improve air quality
- Used as back-up capacity to ensure the security of supply
- Increase of flexibility of CHP plants and incinerators for electricity dispatching

Thermal Storage in Buildings

Two methods are used for DHW preparation in buildings supplied by LTDH networks. These are:

I. Instantaneous heat exchanger units (IHEU)
II. DH storage tank unit (DHSU)

Both function adequately at low supply temperatures. IHEUs heat water at the moment of demand while DHSUs heat DHW slowly over time and store it in a domestic buffer tank until it is demanded [3]. When using IHEUs, the preparation coincides with the use, creating some daily heat load variations. With DHSUs, daily load variations are not so pronounced. Figure 11 below shows a schematic of a DHSU.

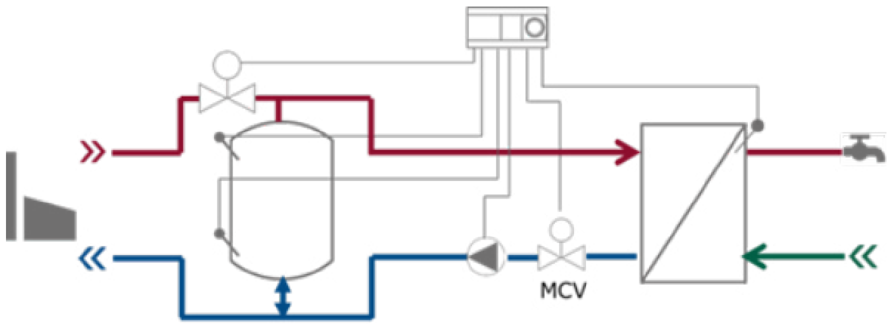

Figure 11: A schematic of a typical DHSU

Although DHSUs reduce peak demands, heat loss from the storage tanks can counteract the positive effects of peak load reduction. This was examined in the case study below.

Example: Lystrup, Denmark

Both heat exchange units were compared in a LTDH network in Lystrup, Denmark which supplies 40 low energy terraced houses. This project involved installing IHEUs and DHSUs in different sections of the network and then comparing performance. A diagram of the network showing the areas with each connection can be seen below.

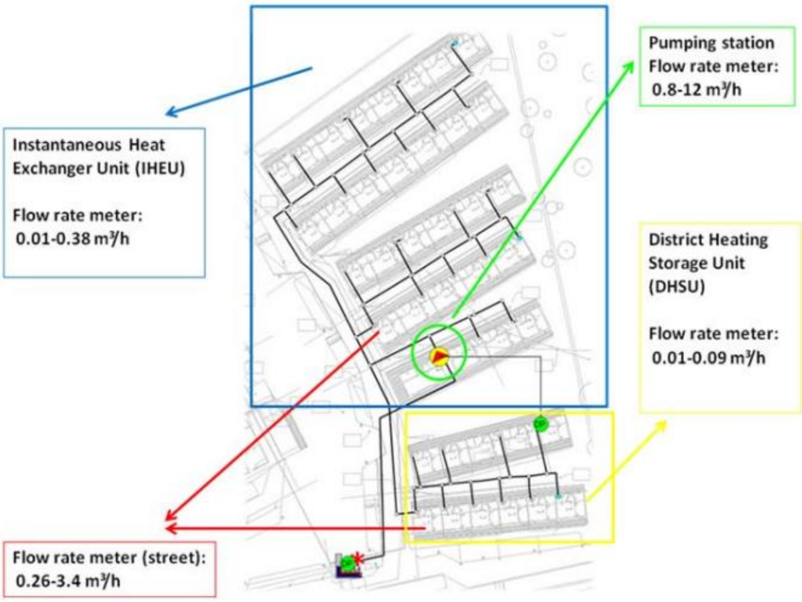

Figure 12: A schematic of the Lystrup LTDH network outlining the areas fitted with either IHEUs and DHSUs

Although the DHSUs offered the benefits of smaller service pipe diameters and the ability to shift peak loads, the overall distribution losses where greater due to heat losses from the storage tanks. This highlights that heat loss from storage tanks should not be neglected. It also demonstrates the importance of considering the overall performance of the network when selecting a DHW system [6].

Seasonal Storage

As shown in figure 10, there are significant difference in loads between seasons. Seasonal thermal energy storage can reduce peak energy demands between season by storing excess thermal energy over months. It is particularly popular in DH networks powered by solar thermal energy sources. This has been demonstrated in a LTDH network in Okotoks Canada [3].

Example: Okotoks Canada

Here, borehole thermal energy storage (BTES) is used for seasonal energy storage in a LTDH network supplied by solar energy. This system consists of 144 boreholes drilled to a depth of 35. A long plastic U bend pipe is inserted into each borehole. When there is additional solar thermal energy available, it is pumped to the centre of the BTES and through the U bend pipes. The heat is transferred to the surrounding soil and rock and cool water exits the BTES. Conversely, when the network requires thermal energy, cool water is pumped into the BTES to absorb heat. A diagram of this storage system is shown below.

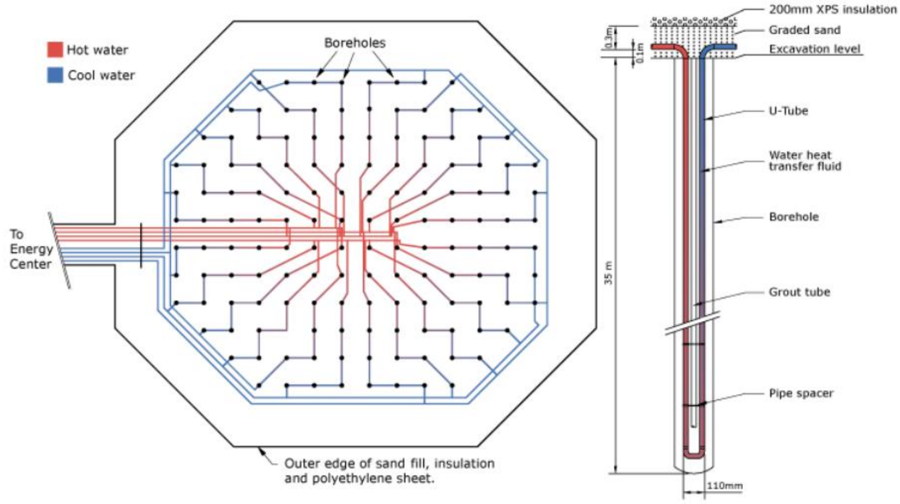

Figure 13: A diagram of the BTES used

The BTES absorbs about 2500 GJ of solar energy annually and has a measured efficiency of 35-55%, and has a much higher energy efficiency per m^2 than solar PV. The system works well and allows LTDH to be supplied with about 90% annually. However, this system is expensive, costing 620,000 CAD$.

Heater Technology

All energy efficient buildings, connected to 4GDH, require some form of water-based heat delivery system meet space heating demands. In this section, three types of heater technology that can be applied to energy efficient buildings are discussed, namely:

- Radiators
- Large surface heat emitters
- Forced air heating

Radiators

Radiators are the most common technology used for space heating. In new buildings, they are usually designed to match LTDH temperature requirements. In older buildings, they are mainly designed for higher supply temperatures than LTDH, but radiators could be adapted for LTDH connection. There are three options to reduce supply temperature in existing buildings which use radiator technology.

- Reduce the temperature as much as possible without any modifications. This approach can often work as many radiator systems in older buildings have are oversized.
- Replace the existing radiators with low temperature radiators - bigger surface areas
- Apply building retrofits to save energy. By reducing the heat power needed to reach thermal comfort, existing radiators can be supplied at low temperatures. If this approach is combined with replacing radiators, supply temperatures can be reduced even further [9].

Example: Slough (United Kingdom)

This standalone LTDH network was constructed in 2010 to heat two apartments and eight terraced houses. All ten dwellings are low energy building achieving Code for Sustainable Homes (CFSH) Level 6 rating. The DH network was designed to operate at a supply temperature of 55°C and is powered by a 30kW biomass boiler, two 17kW ground source heat pumps, a 40kW air source heat pump and 20m² of evacuated tube solar thermal.

Each dwelling consists of a single large radiator in the building lounge and towel rail radiators in the bathrooms. The radiators have pre-settable thermostatic radiator valves (TRV) which ensures the design flow rates of the radiators of 55/35°C, are not exceeded. In addition to the radiators, a Mechanical Ventilation Heat Recovery (MVHR) unit is connected in series after the radiators. The supply temperature of the network was in the region 51°C as opposed to the 55°C which was un-intended. This was largely due to oversized piping resulting in distribution losses and heat loses in above ground piping due to lower standards of insulation being used here.

Radiators: Key Points

The low temperature radiators have provided good thermal comfort to residents however it was deemed that low energy houses should have radiators in each room to ensure even distribution of heat and control of individual room temperatures. The use of TRVs ensured that the return temperature leaving the radiator was sufficiently cool. TRVs achieve this by measuring the room temperature and adjusting the flow rate of hot water entering the radiator accordingly [3].

Large Surface Heat Emitters

Large surface heat emitters are systems whereby the heating system is integrated within the building envelope. Examples include:

- Underfloor Heating
- Wall heating
- Ceiling heating

Of these systems, underfloor heating is the preferred choice for occupants as it provides the best thermal comfort. Large surface heat emitters operate at low supply temperatures making them very suitable for LTDH connection. Underfloor heating can operate at supply temperatures as low as 35°C with maximum supply temperature requirements typically around 40 – 45 °C. This can be comfortably met by 4GDH supply. The high thermal capacity of concrete floors and walls also enables peak thermal loads to be reduced [1, 13].

As these systems are embedded in the building envelope, retrofitting of such systems may prove difficult particularly for concrete, or tiled surfaces. The maintenance of large surface heat emitters can also prove challenging for this reason [9]. A solution to retrofitting underfloor heating into existing energy efficient buildings may lie in the floating floor concept. This involves laying floor panels on top of the existing timber or solid floors. These panels contain pre-grooved pipe slots and heat emission plates to ensure the even emission of heat from the surface. This concept allows underfloor heating to be installed without having to alter the existing surface. Floating floors also enables easy access to the system for maintenance [14].

Forced-Air Heating

Forced-air heating has the benefit of providing both SH and ventilation to buildings. It is particularly popular in North America. For comfort reasons, and because warm air rises to the ceiling, the supply air must not be too warm. This technology is compatible with LTDH as demonstrated by the case study below [3].

Example: Okotoks (Canada)

This DH network provides space heating to 52 detached two-story homes. The network receives 90% of its energy from 2,293 m² of flat plate solar collectors, installed onto the garage roofs and homes. The solar energy absorbed by these panels is stored underground or in short-term storage tanks until there is a demand at which point it is distributed through the DH network to the houses. The supply temperature of the network is about 40°C and around 32°C return. A schematic of this network is shown in figure 14 below [3].

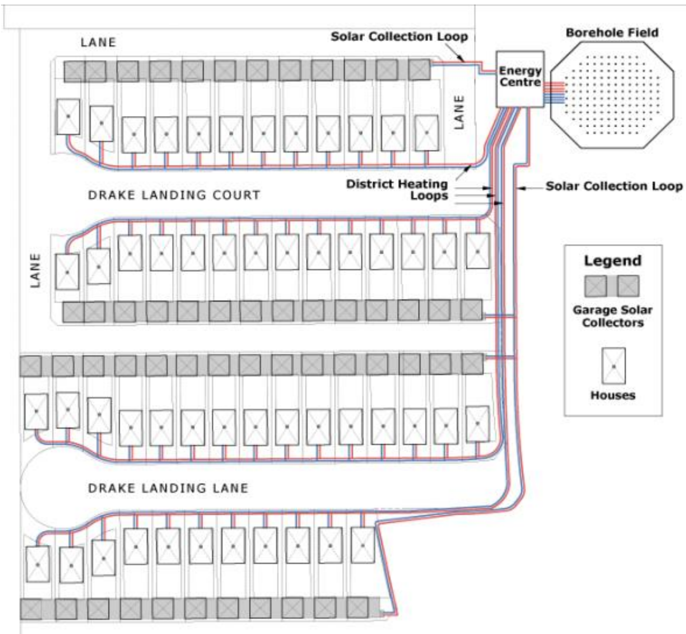

Figure 14: A plan of the Okotoks LTDH network

DHW is supplied by standalone solar hot water systems installed at each house which are backed up by gas powered water heaters.

An integrated air handler and heat recovery unit supplies forced-air heating and fresh air to the houses on the network. These units incorporate fans with electronically commutated motors and water-to-air heat exchangers. A water to air heat exchanger is used to transfer heat supplied by the DH network into space heating in the houses. The DH supply heats a coil, over which a fan blows air, heating the air and distributing it through the home. A schematic of this system is shown below.

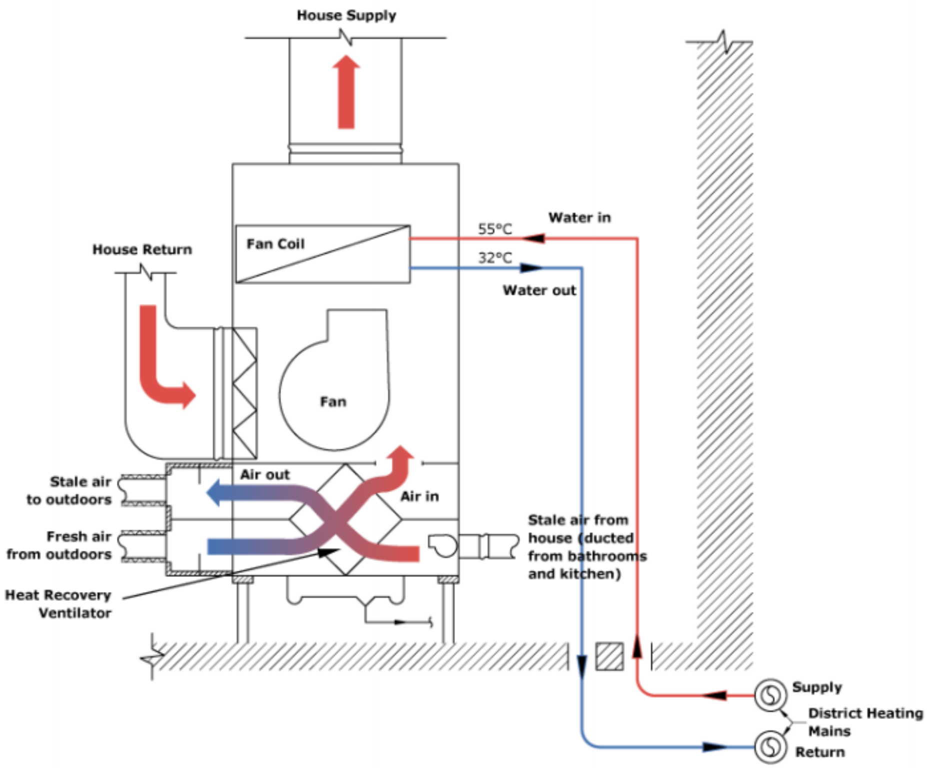

Figure 15: A schematic of the forced-air heating system used in the houses

A thermostat is used to regulate the flow of DH water through the coil. These units adapt the conventional North-American, air-based space heating systems to the requirements of the low temperature district heating supply. In doing so they replace the standard gas fired furnace. This case study shows that this technology is compatible with LTDH however gas-powered boilers were required at times of peak demand here.

Connection to Existing, Extended and New 4GDH Networks

The following paragraphs will focus on three different situations of connection of energy efficient buildings to 4DHC and will give examples of some implementations.

In Existing District Heating Systems

Example: Høje Taastrup (Denmark)

This project involved converting an existing DH network to a LTDH network. This DH network supplies SH and DHW to 75 detached brick houses in the suburb, Hoeje Taastrup near Copenhagen. The existing DH network performed poorly and had annual network heat losses between 38-44%. Consequently, it was expensive for its customers prompting some to use wood-burning stoves.

It was decided to replace this poor performing network with a new LTDH network. The 75 houses already had underfloor heating as space heating system. This made LTDH very suitable for these houses as underfloor heating has a low temperature demand in comparison to traditional radiators. The existing DH network was supplied by the local district heating utility in Hoje Taastrup Fjernvarme via a central heat exchanger. A new LTDH network was designed with the aim of reducing losses to 15% by:

- Improving pipe insulation specifications
- Reducing supply and return temperatures
- Reducing media pipe dimensions and lengths

The new LTDH operates at a supply temperature of about 55°C. The return water of the nearby high temperature network is used as the main supply for the LTDH network. When the temperature of the return supply is not sufficient, a portion of hot water from the high temperature network is added through a mixing shunt. This is layout is demonstrated in the schematic below.

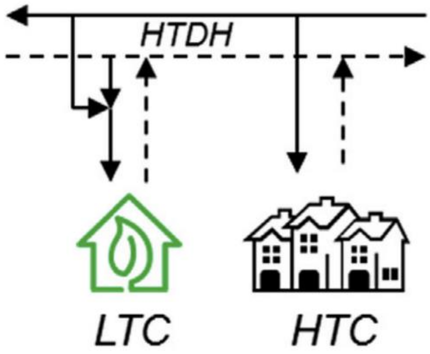

Figure 16: A diagram demonstrating the optimisation used in this LTDH network

Connecting to Existing Networks: Key Points

This case study is an example of a poorly performing DH network being successfully upgraded to a LTDH network. The SH and DHW demands of the customers were satisfied. The energy efficiency target was also met with heat losses measured between 13-14%. This was a 28% reduction in losses compared to the previous network.

In New 4DHC

The integration of energy efficient building retrofits along with 4GDH can make DH feasible in areas of low heat demand.

Example: Lystrup (Denmark)

As was mentioned in chapter 2, a new area in Lystrup, consisting of 40 low energy houses and a communal building, was connected to a LTDH in 2010. The DH network supplies the building hot water and space heating. The key data of the DH measured in 2012 are displayed in the following table (*from CELSIUS Case study*).

Table 3: Key data relating to the Lystrup 4GDH network

Parameter	Value
Total heated area	4,115 m²
Supply temperature (design/measured)	55 / 52.1 °C
Return temperature (design/measured)	30 / 33.7 °C
Domestic Hot Water temperature	45 °C
Space Heating design temperatures (supply/return)	55/25 °C
Trench length	723 m
Supplied heat	282.6 MWh
Delivered heat	232 MWh
Distribution losses	17.9 %

The linear heat density of the area is very low at 0.3MWh/m but this project was made feasible through several 4GDH measures that were applied, such as:

- Applying twin-pipes to minimize distribution losses.
- Installing domestic hot water systems that function at supply temperatures as low as 50°C
- Direct space heating connections.
- Installing Low temperature radiators and underfloor heating

Example: The Greater London Authority (GLA)

The GLA conducted a study into building retrofitting of 4th generation DH connection. This study found that in The Greater London Area, low efficiency buildings show a better cost effectiveness than high efficient buildings for DH connection. The most cost-effective buildings for DH connections are:

- Low and medium efficiency electrically heated high-rise flats
- Low-rise flats and houses
- Large electric heated offices

Surprisingly, gas heated flats, houses and large retail buildings have a medium cost effectiveness for DH retrofitting. This could be due to very low gas price but could evolve significantly in the coming years as gas price is largely unstable and subject to change (and rise) quickly. Dense urban areas, with low efficiency buildings, obviously represent a higher heat density and are therefore more cost-effective than other areas with high efficient building and lower heat density.

Cost Comparison: Energy Efficient Building Connected to 4DHC vs Old Buildings Connected to 4DHC

The cost of connection of district heating to existing heating stock depends on many factors;

- Number of houses connected – Individual connection to a house are the most expensive option as there would be more trenching required so shared connection would be the most economic option but would require numerous neighbours to consent to connection.
- Current heating system – In a gas heated house the existing radiator could be maintained depending on the radiator size. The existing boiler would need to be replaced by a Heating Interface unit (HIU) with a pump, control valves and meter on the primary side. This would indirectly connect the house to the district heating system to reduce contamination and leaks. Electric heating systems will require a change to a wet heating system which will require much more retrofitting. A Celsius study in London found that an electrically heated 10 storey high rise low efficiency flats with 40 dwellings would have an estimated retrofit cost of €360,000 while the gas system equivalent would cost an estimated €209,000.
- Energy efficiency – As 4GDH involves a low supply temperature (70 – 40^{0}C). A Celsius study in London on connecting existing building to district heating found at heating supply temperatures of 70 °C approximately 99% of annual heat demand can be met, at 60 °C between 96%-99%, at 50 °C between 86%-98% and at 40 °C this can be as low as 50%-92%. These percentages were determined by a houses energy efficiency [15]. So 4GDH would only be suitable in low efficiency houses if a suitable efficiency upgrade is made. This is shown in table 5 which describes the annual heat demand that would met by a supply temperature of 40°C corresponding to efficiency categories which are stated in table 4. The study found that an additional domestic retrofit costing between €120/m² to €179/m² would reduce unmet demand from 40% to 5%, while in commercial buildings they found there was still a need for a backup source of energy. The higher the efficiency of the house the less retrofit measures would be required.

However, the lower the efficiency the greater the cost effectiveness of the retrofit in relation to energy saved.

Table 4: U-values related to the energy efficiency categories set out in Table 5

	Walls	Windows	Roof	ACH
Baseline	Solid walls, U=2.10	Single glazed, U=2.10, g=0.85	50-150mm, U=0.4	1
Half air infiltration	Solid walls, U=2.10	Single glazed, U=2.10, g=0.85	50-150mm, U=0.4	0.5
U-values to Part L1B	Insulated, U=0.30	Double glazed, U=1.4, g=0.85	300mm, U=0.11	1
U-values to Part L1B + half infiltration	Insulated, U=0.30	Double glazed, U=1.4, g=0.85	300mm, U=0.11	0.5
Passivhaus U-values	Insulated, U=0.12	Triple glazed, U=0.8	300mm, U=0.11	1
Passivhaus U-values + half infiltration	Insulated, U=0.12	Triple glazed, U=0.8	300mm, U=0.11	0.5

Table 5: Heat demand met by a supply temperature of 40^{0}C

Low efficiency house	Percentage of annual heat demand	
	Baseline	40 flow
Baseline (no retrofit measures)	100%	59.70%
Half air infiltration	100%	68.70%
U-values to Part L1B	100%	86.40%
U-values to Part L1B + half infiltration	100%	95.90%
Passivhaus U-values	100%	94.60%
Passivhaus U-values + half infiltration	100%	99.80%

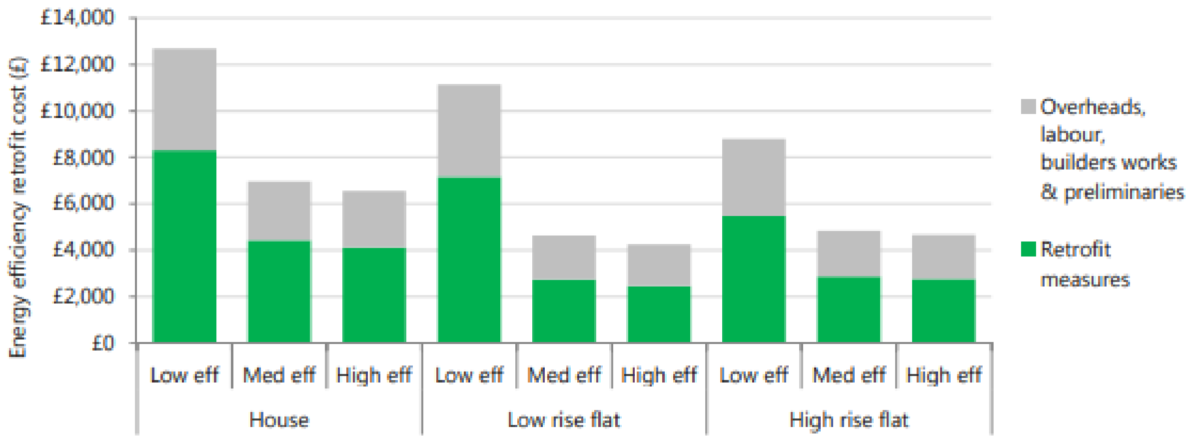

Figure 17: Capital costs for the domestic energy efficiency scenario of "U-values to Part L1B + half infiltration

Table 6 shows the London feasibility study with a DH price with little to no subsidy. It shows that the unit price of each fuel will drive feasibility and in certain cases 4GDH will not be possible without subsidy. However, the feasibility of 4GDH needs to be studied in a case by case manner.

Table 6: Payback period on converting to a DH system with supply temperature of 40⁰C in London [15]. Gas price = 45 €/MWh, electricity price = 170€ /MWh and DH price= 73 €/MWh

Type	Gas Boiler conversion (Payback Period)	Electric heating conversion (Payback Period)
Large office (Low Eff)	none	4 years (Heat Pumps)
Large office (Med Eff)	none	14 years (VRF)
House (Low Eff)	none	14 years (Panel Heaters)
House (High Eff)	none	39 years (Panel Heaters)
High Rise Flats (Low Eff)	38 years	14 years (Panel Heaters)
High Rise Flats (High Eff)	39 years	31 years (Panel Heaters)

An IEA Report analysed an example of a Danish housing, built in the 1970's which is already connected to 3rd Generation DH being upgraded to connect to 4th Generation DH. The heating system has a supply/return temperature of 70⁰C/40⁰C which maintains the room temperature at 20⁰C. The cheapest solution for retrofit was the replacement of the windows as they were over thirty years old so were due replacement.

Table 7: U Values(W/m² K) for the case study [3] and U Values for Irish Building Regulation [16]

Construction/Case study	Case study (U values)	Ireland Existing Buildings (U values)	Ireland New Buildings (U values)
External Walls	0.31	0.35	0.21
Roof	0.33	0.25	0.2
Floor	0.4	0.45	0.21

Table 8: Case study Window Replacement options [3]

Case	**Measures**	**Overall window U-value [W/m²K]**
1	No measures	2.5
2	New glazing, old frames	1.4
3	New low-energy windows (frame included)	0.9

Table 9: Heat demand for the different replacement options in table 8 [3]. Temperature for SH corresponds to supply/ return temperature in 0C. Tout corresponds to the outside temperature.

Case	Peak power [kW] for -21°C	Energy demand for SH [MWh/year]	Temp. for SH	Flow rate [L/min]	Temp. for SH	Flow rate [L/min]	Temp. for SH	Flow rate [L/min]	Peak power [kW] for 0°C
			T_{out} = -21°C		T_{out} = 0°C		T_{out} = 0°C		
1	5.8	10.49	70/40/20	2.75	60/29/20	1.47	50/34/20	2.84	3.23
2	5.0	8.3	65/35/20	2.36	60/26/20	1.16	50/29/20	1.87	2.79
3	4.5	7.55	65/32/20	1.93	52/25/20	1.31	50/26/20	1.47	2.51

Tables 8 & 9 above show that replacement of windows to 1.4 W/m² K (U value) can greatly reduce the heat demand and flow rate needed for the DH system to maintain a room temperature at 20^{0}C. Table 9 also indicates that if outside temperature is above or equal to 0^{0}C then even without modern windows the existing housing stock could function efficiently with supply of 60^{0}C. This case study emphasises that deep retrofitted isn't needed to lower heat demand to make 4GDH feasible. The conclusion is that the greater the efficiency of the house the lower the flow rate, supply and return temperature making the DH more efficient so in turn more feasible and improves environmental benefits

Key Points

- Electric heated houses require a deeper retrofit than gas boiler to convert to a DH
- The lower the supply temperature the higher the unmet head demand and greater retrofit needed in the existing housing stock
- DH economic feasibility will rely on fuel prices and the level of subsidy
- Deep retrofit isn't needed for existing building to be compatible to 4GDH
- New buildings build to regulation will be compatible with 4GDH

Chapter 2 References

1. Lund, H., et al., 4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems. Energy, 2014. 68: p. 1-11.
2. Connolly, D., et al., Heat Roadmap Europe 2, in Second Pre-Study for the EU27. Department of Development and Planning, Aalborg University. 2013.
3. Dalla Rosa, A., et al., Toward 4th Generation District Heating: Experience and Potential of Low-Temperature District Heating, in Experience and Potential of Low-Temperature District Heating. 2014, Technical University of Denmark,.
4. Möller, B. and S. Werner, Quantifying the Potential for District Heating and Cooling in EU Member States, in Stratego. 2016.
5. Gartland, D., Dublin City Spatial Energy Demand Analysis. 2015, Codema.
6. Christiansen, C.H., et al., Results and Experiences from a 2-Year Study with Measurements on a Low-Temperature DH System for Low Energy Buildings. 2012.
7. COHEAT LTD, DECC Heat Networks Demonstration SBRI., in COHEAT 5G Heat Network Demonstration. 2014: United Kingdom.
8. SPECIAL, Good Practice Example: City of Västerås's energy and climate adaptation strategy. 2016.
9. Hesaraki, A., A. Ploskic, and S. Holmberg, Integrating Low-temperature Heating Systems into Energy Efficient Buildings. 6th International Building Physics Conference (Ibpc 2015), 2015. 78: p. 3043-3048.
10. Gadd, H. and S. Werner, Heat load patterns in district heating substations. Applied Energy, 2013. 108: p. 176-183.
11. Gadd, H. and S. Werner, Daily heat load variations in Swedish district heating systems. Applied Energy, 2013. 106: p. 47-55.
12. Cities., C.S. Heat Hub - Storage. 2018 [05/04/2018]; Available from: http://celsiuscity.eu/Demonstrator/heat-hub-storage/.
13. Schmidt, D., et al., Low Temperature District Heating for Future Energy Systems. 15th International Symposium on District Heating and Cooling (Dhc15-2016), 2017. 116: p. 26-38.
14. British Plastics Federation, Warm Water Underfloor Heating System, in Guidance Notes. 2017.
15. Dowson, M., Connecting Existing Buildings to District Heating Networks. 2016, BuroHappold Engineering,.
16. Irish and Department of Housing, Conservation of Fuel and Energy – Dwellings Technical Guidance Document. 2011.

Connection Optimisation

Heat Exchanger Connections

Substations are a key component of district heating networks. They represent the transfer of thermal energy from the grid to the end user. Substations can connect individual dwellings or multi-storey buildings to 4GDH networks. Substations facilitate the transfer of thermal energy from the network to the end user for both space heating (SH) and domestic hot water (DHW) uses. Different substation configurations used to achieve this are described in this section.

Space Heating

Space heating systems can be connected directly or indirectly to a DH network. Direct connections supply SH systems directly from the grid. An indirect connection uses a heat exchanger to provided thermal energy to the SH system. A plate heat exchanger is typically used for indirect connections. Figure 18 below shows a schematic of both types of connections

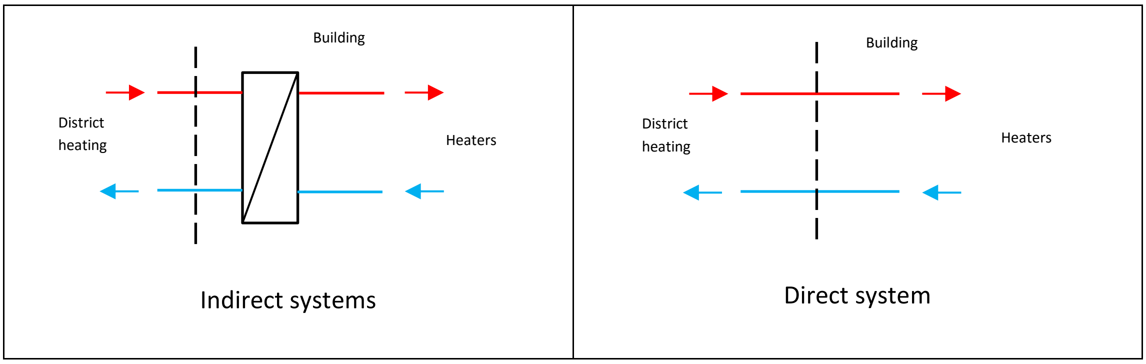

Figure 18. A schematic of direct and indirect space heating systems.

Table 1 below shows the advantages and disadvantages of direct and indirect space heating systems [1].

Table 10. The advantages and disadvantages of direct and indirect space heating systems.

	Advantages	**Disadvantages**
Direct system	▪ No decrease in temperature between the district heating and the space heating system	▪ DH and building's heating system has the same pressure ▪ Anticipation of leakage
Indirect systems	▪ Clear separation of district heating network and building installation. ▪ Network can operate at pressures independent of building installations. ▪ Easier management in case of leakage	▪ Higher supply temperatures required. ▪ More expensive substation

Domestic Hot Water Preparation

As was mentioned in chapter 2, there are two types DHW preparation methods used in 4GDH substations. These are Instantaneous heat exchange units (IHEU) and district heating storage units (DHSU). IHEUs are sized based on the network supply temperature. Due to the low supply temperatures of 4GDH, IHEUs with high efficiency and low operating temperature differences should be applied. Plate heat exchanger is usually applied to achieve this. DHW temperature is controlled using a flow controller with a temperature sensor.

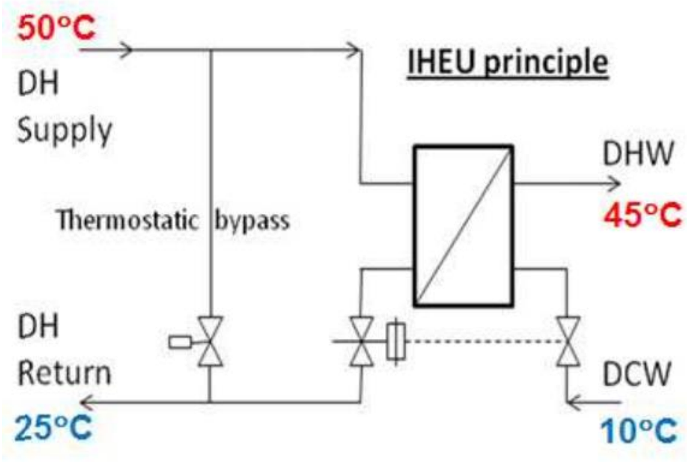

Figure 19: A schematic of an instantaneous heat exchange unit [1]

DHSUs consist of a storage tank which is applied as an energy buffer. For low temperature applications, the storage tank is usually placed on the primary (DH network side). This is done to minimise the risk of legionella. The volume of the storage tank is sized based on the total daily DHW draw-off profile [2].

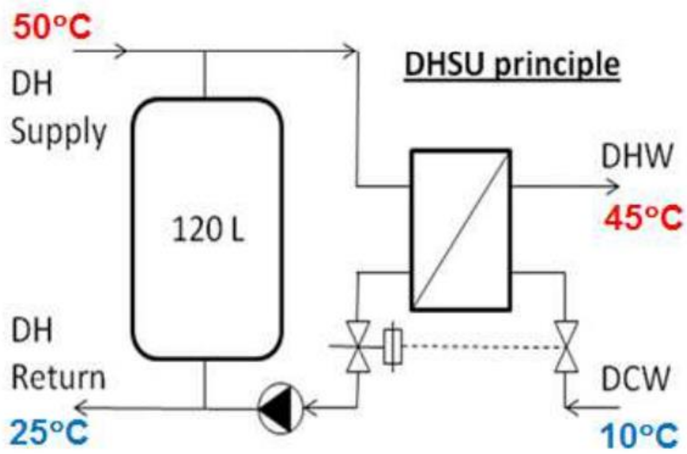

Figure 20: A schematic of a district heating storage unit [1]

Table 11: The advantages and disadvantages of IHUEs and DHSUs [1, 2]

	Advantages	Disadvantages
Instantaneous heat exchange units	• Simpler Configuration • More compact • Cost saving solution	• Larger service pipe diameters
District heating storage units.	• Shaves peak loads • Smaller charging flow allows for service pipes with smaller diameter • Reduced heat loss from service pipes	• Increased legionella risk • Heat loss from storage tank outweighs savings in network losses

Substation Example: Danfoss DSE Flex

Within a substation, various configurations can be applied to optimise substation performance. Below is an example of a substation designed by the Danish company Danfoss. This substation uses the return flow from an indirect SH system to provide thermal energy for the DHW heat exchanger. A schematic of this system is shown below [3].

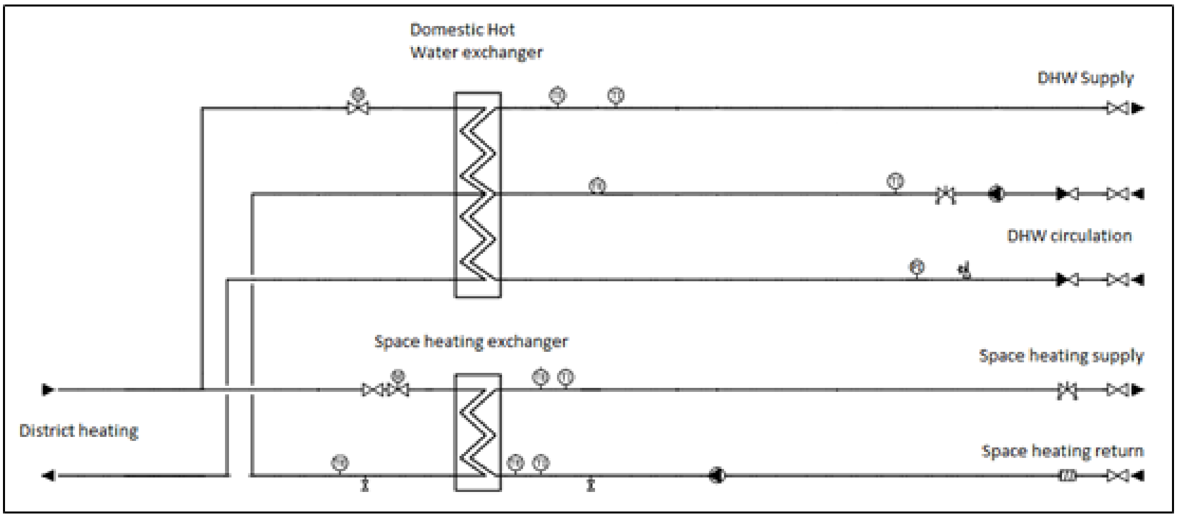

Figure 21: Danfoss DSE Flex substation diagram [3]

In this substation design, the space heating return flow can supply the DHW exchanger. This layout could be implemented if the space heating temperature requirement is higher than the DHW temperature requirement, particularly if space heating provides return temperature above DHW return temperature. This layout reduces the total heat provided by the DH network to the substation. It also reduces the network return temperature.

Multi-Storey Buildings

Flat stations are the state-of-the-art solution for providing LTDH to multi-storey buildings. Flat stations involve each dwelling in a multi-storey building having its own compact substation for DHW preparation and SH. This avoids the requirement for large hot water circulation systems and thus reduced heat loss. This reduces supply temperature requirements. Other advantages of the flat system concept are that it enables simple and precise metering of each flat's heat consumption and that it allows each occupant to have complete control over SH and DHW preparation [1].

IHEUs are typically applied due to limited space [2]. Below is a schematic of a flat station installed in a multi-storey building.

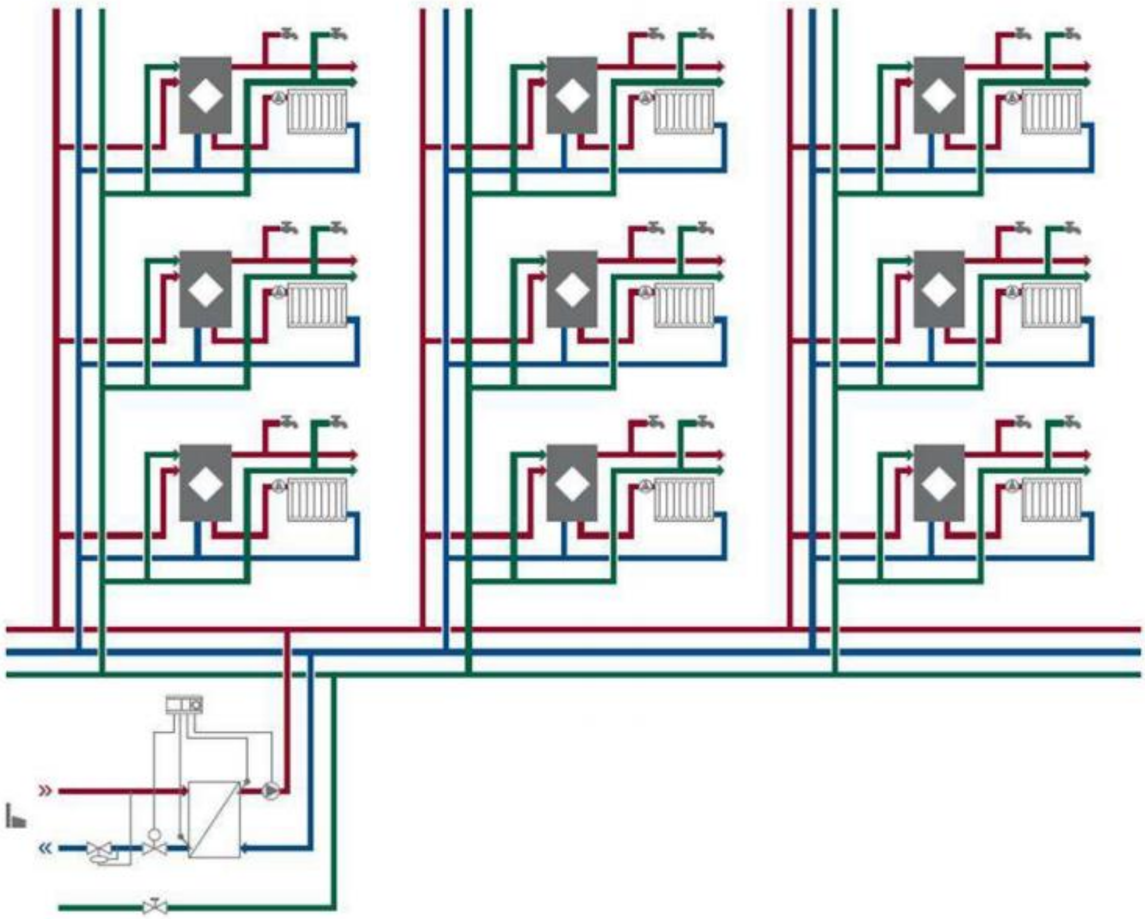

Figure 22: Flat stations installed in a multi-storey building with domestic hot water is produced in each flat

Legionella

A significant issue in the development of 4GDH is preventing the occurrence of legionella. Legionella development is problematic in stagnant water below 50°C. Legionella has traditionally been safeguarded against in DHW through regulations requiring high hot water temperatures. As a result, most European countries require the district heating supply temperature to be at least 60 °C. These regulations have become a barrier to the development of LTDH networks [4]. Some alternatives to legionella prevention other than thermal control in DH networks include [5]:

- Installing decentralised substations with IHEUs
- Applying micro heat pumps for local temperature elevation
- Installing electric heating elements to boost DH supply temperature
- Reduce the volume of water flowing through pipes.
- Apply chemical treatment such as ionization, chlorine of chlorine dioxide treatment

Connection Optimisation: Key Specifications

Table 12 below shows some key details relating to the connection of buildings to LTDH networks in existing networks.

Table 12: Key connection specifications for buildings connected to existing LTDH networks

Network	Supply/Return Temp (C°)	Building Type	Heater Technology	SH Connection	DHW Connection
Lystrup, Denmark	55/25	New Build Terraced	Radiator & Floor Heating	Direct	IHEU & DHSU (Comparison)
Okotoks, Canada	40/32	Detached	Forced-air heating	Water to Air Heat Exchanger	Stand alone system
Høje Taastrup, Denmark	55/40	Existing Detached	Floor Heating	IHEU (plate)	IHEU (plate)
Slough, United Kingdom	51/34.4	Mixture	Radiator	Direct	IHEU (plate)
Tilst, Denmark	60/40	Existing Detached	Radiator	Direct & Indirect	DHSU

Example: Høje Taastrup (Denmark)

As mentioned in chapter 2, the LTDH network in Taastrup, Denmark involved the conversion of a poor performing, conventional DH network to LTDH. The substation installed in each dwelling before the conversion were DHSUs with storage tanks between 110 - 150 litres. These units performed badly, resulting in complaints from network customers. The network renovation involved the installation of new, Danfoss Redan Akvalux II VX, substations at each dwelling.

These parallel plate, IHEUs provide indirect SH and DHW connections for customers and have a design capacity of 32.3 kW. They are capable of supplying DHW at 45°C at supply temperatures as low as 50 °C. Legionella risk is eliminated in this design by ensuring a maximum predetermined flow rate, through the heat exchanger, is not exceeded on either the primary or secondary side. This connection arrangement is very relevant in terms of DH optimisation as it demonstrates how IHEUs can effectively meet SH and DHW demand, even at low supply temperature. Below is the table of key data for Høje Taastrup DH network [2].

Table 13: Key data for the Høje Taastrup LTDH network

Parameter	Value
Year of construction	2012
Number of houses	75
Supply temperature (design/measured)	55-52 / 55.0 °C
Return temperature (design/measured)	27-30 / 40.3 °C
DHW temperature	45-50 °C
Supplied heat	1,228 MWh
Delivered heat	1,052 MWh
Distribution losses	14.3 %

Chapter 3 References

1. Olsen, P.K., et al., Guidelines for Low-Temperature District Heating. 2014.
2. Dalla Rosa, A., et al., Toward 4th Generation District Heating: Experience and Potential of Low-Temperature District Heating, in Experience and Potential of Low-Temperature District Heating. 2014, Technical University of Denmark,.
3. Danfoss, DSE FLEX Operating Guide. 2018.
4. Yang, X.C., H.W. Li, and S. Svendsen, Decentralized substations for low-temperature district heating with no Legionella risk, and low return temperatures. Energy, 2016. 110: p. 65-74.
5. Yang, X.C., H.W. Li, and S. Svendsen, Alternative solutions for inhibiting Legionella in domestic hot water systems based on low-temperature district heating. Building Services Engineering Research & Technology, 2016. 37(4): p. 468-478.

Encouraging 4DHC

Contracting Method

Example: Gothenburg DH

In Gothenburg DH, Göteborg Energi offers five different agreements to its customers. Some agreements help to improve DH efficiency by adjusting the heaters, installing temperature sensors and learning about the building's use. Göteborg Energi help the building's owner to make savings by giving advice on technical improvements. The energy savings could reach up to 50% in some buildings. This type of agreement encourages energy savings and so 4DHC as it helps to reduce heat consumption and to optimise temperature in the building. The graph below describes the 5 types of agreements offered by Göteborg Energi. In the 4 first agreements, Göteborg Energi advices the customer on technical improvements to reduce energy. In the Green Partner agreement, a 25% energy saving plan is set up at the beginning of the contract.

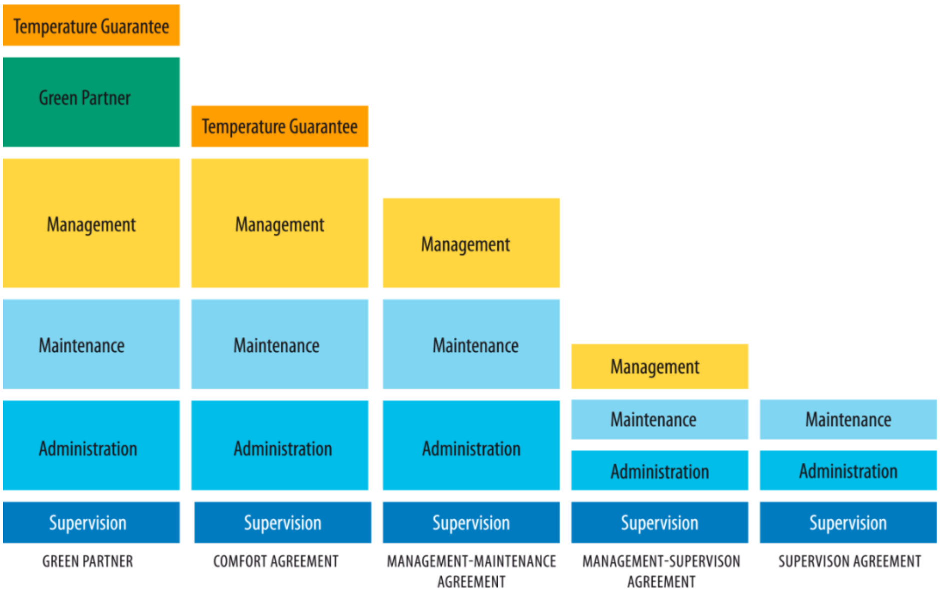

Figure 23: Göteborg Energi agreements

Support schemes

Existing support Schemes for Energy Efficiency Retrofit Integrates 4DHC Connection

Following the EU Energy Performance of Building Directive, European countries have begun to translate the European directive into local legislation. In Sweden, the Swedish Building Codes define a calculation of energy efficiency in buildings based on delivered energy. This calculation discriminates DHC and favours individual heat pumps. Other countries (Ireland, France, Germany, Finland) have based their building energy efficiency calculation on primary energy, which is fairer, and better consider DHC use. This directive and its applications are a first step of energy efficiency in buildings and 4DHC integration.

Key issues and solutions

Article 14(1) of Directive 2012/27/EU requires all members states to submit a comprehensive assessment of the potential for the application of high efficiency CHP and efficient district heating and cooling to the European Commission by 2015. However, despite this, policy in district heating and cooling in many North-West European remains a barrier to the system implementation.

Country	National Heating Plan	Regional Heating Plans	Regulatory Framework for DH	Tariff for Renewable heating	4DHC suitable U – Values required in new builds	Policy on upgrading district heating systems to 4th Gen	% of heat demand provided by district heating
United Kingdom	x	x	x	x	x		2%
Ireland				*	x		0.8%
France	x			?	x	**	6%
Netherlands	?	x	x	x	x		4%
Belgium		x		?	?		?
Sweden	x	x	x	x	x	X	?

* Planned soon

** Plans on how to modernise older DH systems to 4th Generation are mandatory.

Ireland

There is currently no national heating plan or any supports for any form of district heating in Ireland. A Sustainable energy authority of Ireland 2015 report which was required under Article 14(1) of Directive 2012/27/EU found that 90% of Ireland’s heat density is too low to support district heating leading to no calls for national planning for district heating [1]. The report however did not look at the change in economic feasibility if the potential of 4th Generation district heating and using waste energy as a source is considered.

There is some subsidy provided to CPH plants which has an indirect positive effect on district heating. The Renewable Energy Feed- in tariff (REFIT) 3 schemes provides a fixed price for electricity for recipients in planned Anaerobic digestion CPH, Biomass CPH and biomass co -firing plants for 15 years. This encourages using waste heat, but it doesn’t stipulate it must be used in district heating schemes. Also, Ireland provides grid priority to renewable electricity generators which includes those that run high efficient CPH plants. Previous heating schemes in Ireland were mostly based on bioenergy including the ReHeat Scheme which targeted at biomass, solar and geothermal heating in commercial, industrial, public and community facilities providing a certain percentage of the capital costs. However, these schemes never included funding for district heating specifically.

Part L of the Building Regulations Conservation of fuel and energy in Dwellings requires the mandatory use of Renewable Energy Sources - a minimum of 10 kilowatt hours per square metre per annum [2]. However, any waste heat used is not considered, so onsite renewables must be used. The Irish National Energy Efficiency action plan does encourage the use of 4GDH for new developments [3]. The plan also requires all public building to reduce their energy use by 33% by 2020 which has been a driver for energy action plans in the public sector. U

– Values requirements for new building mean they are strongly insulated with heat losses low enough to make it suitable for 4th generation district heating.

The SEAI do provide funding for community energy retrofit schemes which could be used for retrofitting for district heating connection. However, grants for individual households do not include equipment for district heating connection with grants provided for wood chip boilers and heat pumps will discourage district heating as people are locked into the technology for a certain length of time.

United Kingdom

The Future of heating is a British 2012 report detailing a strategic framework for low carbon heat. While the report admits that natural gas will dominate its heating supply into the 2020's [4]. It predicts that district heating will be at the core of the UK's long-term heat strategy helping to reach its 2050 carbon reduction targets. The Government has backed up this plan by releasing regulations around billing & metering [5] and a code of practice for heat networks [6]. Through the Heat Road map project the UK has heat demand, excess heat and heat synergy maps [7].

To contribute to the UK government's 2020 renewable heating targets the renewable heating incentive was launched. The programme provides financial incentives to increase the uptake of renewable heat by businesses, the public sector and non-profit organisations. The non- domestic version provides businesses, the public sector and non-profit organisations quarterly payments over 20 years on eligible installations based on the amount of heat generated. The non- domestic scheme also includes financial incentive to district heating schemes if the heat source is considered renewable. The scheme is available in Scotland, England and Wales but is currently suspended for new applicants in Northern Ireland.

Much like other partners in Heatnet, the development of district heating in the UK is affected by local and national policy. The Scottish Government released heat policy statement committing money towards infrastructure costs of district heating systems [8]. According to England and Wales building standards a feasibility study must be undertaken on the use of high efficiency alternative energy systems to power new developments in which district heating is a possible alternative [9]. Also building which are served by district heating are awarded carbon saving credits which allows building to reach required carbon emission rates. While Northern Ireland doesn't require these studies, it does recommend 4th Generation district heating and cooling be incorporated in low carbon homes [10]. In England, Scotland, Wales and Northern Ireland required U – Values for new building mean these buildings are ideal for 4th generation district heating.

France

In 2016 France released a national heating plan, 'PPE' - the national multi-annual heat strategy and as required under Article 14(1) of Directive 2012/27/EU France designed a national heat map. Through the Heat roadmap project France has an excess heat atlas and heat synergy regions map [7]. ADEME (the national energy agency), oversees a heat fund which provides finance to district heating projects. Also, through this fund it finances research into technical, awareness and economic aspects of 4DHC. France also provides financial incentive to customers of 4DHC through a reduction of VAT on energy bills from 20% to 5.5%.

Regulation for large urban construction project requires a feasibility study be undertaken for the extension or construction of a district heating system as well as other renewable technologies. Thermal regulation for buildings (2012) taking district heating into account as a potential source of renewable energy; based on carbon content of district heating. If the carbon content of a district heating is particularly low, it is then possible to insulate the building less. As mandatory due to the art 14 of the EED, for every new major district heating or every new major plant built in France, there must be a costs-benefits analysis regarding the use of industrial waste heat in the district heating. In 2016, supported by CEREMA, ADEME and AMORCE, the French Ministry for Energy proposed municipalities over 10 000 inhabitants and disposing of no district heating to finance a feasibility study for DH if they decide to build one. Energy savings certificates scheme considers some district heating renovations. Changes in urban planning in 2015 mean local authorities can impose use of a certain percentage of renewable energy for every new building. If this percentage is high, then district heating will in turn be a more favourable solution.

Law on energy efficiency renewable energy systems in 2015 set a target for 2030 of a 5-fold increase in renewable energy and waste heat in district heating. For each region mandatory mapping of district heating and biomass master plans are required on their territories. Local authorities with a district heating system built before 2009 are required to create a 10 years master plan outlining the modernisation of the system and how to integrate more renewables.

Netherlands

Heat networks in the Netherlands have been regulated since 2014 by the heat act. In the Heat Act there is regulation around: maximum tariff for consumers, a permit needed for delivery of heat, financial dispensation when delivery of heat is disrupted and costs of metering. It was set up to protect the consumers with a connection of less than 100 kW heating capacity. These customers also benefit for district heating tariffs funded by government which ensure costs for a household with district heat should not be higher than the costs of an individual condensing gas boiler. Tariffs are also provided for larger customers which covers the full cost of the heat. Through the Heat Road map project the Netherlands has a heat demand, excess heat and heat synergy maps [7].

In the Netherlands emphasis is put enabling and encouraging local authority to take the lead in creating district heating schemes. Many local authorities have already designed heating plans with the 2016 energy agenda stating that more responsibility would be given to local authorities to decide on local energy systems. Motivation for the 2016 energy agenda, which is still under construction, the need for heat networks to be used to reduce CO2 emissions and a need to transform the laws around heat networks to facilitate this. To achieve this, it is proposed to stop connecting new areas to gas infrastructure, change mandatory gas connection to an energy connection, for regulation of heat networks in same way as electricity and gas networks.

Building code (Bouwbesluit 2012) makes numerous mentions of heat networks (district heating). In Article 6.10 it states that a house will get a mandatory connection to a heat network when the network is present within 40m, when no equivalent alternative is found. However, this is only valid if the municipality has described this in the local heat plan. Also, in the code is the positive effect district heating has on energy performance calculated via Energy Performance Coefficient (EPC).

Belgium

In Belgium, there is no national district heating plan or approach with most renewable energy policies being completely regionalised. However, related to heat networks the federal government is mandated to define maximum prices, government assignments, and consumer rights.

In Wallonia there is no strategy for renewable heat with subsidies for heat networks being abolished in 2014. However, in Flanders the 2017 “Warmteplan 2020” (Heatplan) was developed with the aim to produce 9.197

GWh through ‘green’ heat. It is forecasted that only 8.765 GWh of green heat will be produced by 2020 within current policies so additional policy is required. In 2016 the Flemish government released **Witboek: Beleidsplan Ruimte Vlaanderen** which is strategic spatial transformation plan highlighting the need for district heating and the benefit of incorporating waste heat from industry. The Flemish ‘climate plan 2013-2020” wants to develop heat network as part of decreasing carbon emission with the plan backed by the Klimaatfonds fund. The Flemish government provided extra financial support within the frame of the Flemish Action Plan for Green heat. In 2014 the Flemish government introduced the RenovatiePact with the objective to develop and implement a coherent plan of action that, in a short-, medium- and long-term perspective, will lead to a significant increase of the renovation rate of the Flemish housing stock and will optimize its energy performance to nearly zero energy level.

Chapter 4 References

1. SEAI, Cost Benefit Analysis of the potential for High-Efficiency Cogeneration and Efficient District Heating & Cooling in Ireland. 2015, Sustainable Energy Authority Ireland
2. Irish and Government, Conservation of Fuel and Energy - Dwellings: Building Regulations. 2011, Department of the Environment, Community and Local Government.
3. DCCEA, National Energy Efficiency Action Plan 3. 2014, Department of Communication, Energy and Natural Resources Ireland.
4. DECC, The Future of Heating: A strategic framework for low carbon heat in the UK. 2012, Department of Energy and Climate Change (UK).
5. Government, U., The Heat Network (Metering and Billing) Regulations 2014. 2014.
6. CIBSE, CP1 : Heat Networks: Code of Practice for the UK. 2015, Chartered Institution of Building Services Engineers (CIBSE).
7. Europe, H.R.M. Pan-European Thermal Atlas 4. [cited 2018 31-May].
8. Scottish-Government, Heat Policy Statement Towards Decarbonising Heat: Maximising the Opportunities for Scotland. 2015.
9. MHCLG, Conservation of fuel and power: Approved Document L. 2014, Ministry of Housing, Communities and Local Government (UK).
10. DFPNI, Building Regulations (Northern Ireland) 2012 Guidance. 2012, Department of Finance and Personnel (Northern Ireland).