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TOWARDS NEXT GENERATION DISTRICT HEATING IN FINLAND

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ABSTRACT

District heating has been used as heating energy provider for buildings since the half of 19th century. It evolved together with buildings towards higher energy efficiency. Today the energy production systems, hooked up to the district heating network, are able to produce both heating energy and electricity. In some particular cases, also cooling energy is produced. Nowadays it is extensively used in Nordic countries, especially in Finland; subject of this study. Actually, Finnish district heating is facing important challenges, since new European regulations are coming into play affecting both energy generation methods and building energy efficiency. Basically, buildings are becoming more efficient and renewable technologies more cost-effective. Particularly, buildings consume less heating energy, due to high level of insulation, and adopt low temperature indoor distribution systems. Furthermore, new electrical appliances are penetrating into buildings, generating also cooling loads in summer even in cold climates. In addition to these, new effective technologies are available on the market. All these aspects are inducing the district heating to evolve. This study discusses relevant issues for a smooth transformation of the current Finnish district heating towards the future generation. Authors, after an extensive review of the existing district

heating operating practices and of the promising innovative technologies network integration, suggested possible and realistic technologies integration scenarios.

KEYWORDS

District heating, solar energy, heat trading, zero energy buildings

1. INTRODUCTION

The district heating service appeared in the second half of the 19th century. At that time steam was used as heat carrier; therefore the network had significant losses because of the high operating temperature. Lund et al. [1] discuss the evolution of the district heating in terms of temperature, efficiency and best applied available technologies along the time. Particularly from 1880 up to now, four generations of district heating can be identified. An inversely proportional relation between the efficiency and the temperature embodies the evolution of district heating [1]. In addition, the efficiency of the 4th generation of district heating is boosted by the adopted renewable systems. District heating and district cooling networks can be identified at the district energy distribution level of the 4th generation. In this study authors have considered only the district heating.

On the other hand, the demand side of the district heating consists of buildings built in different period of time. This means that they have different thermal loads and, in particular, they use different indoor space heating distribution systems, which require diverse inlet temperature set points of the heat carrier fluid; generally water. Table 1~~Table 1~~ shows the inlet/outlet design temperature of the common indoor distribution systems and also the building level of insulation associated to them.

Table 1. Inlet/outlet design temperature of the common indoor distribution systems.

Indoor distribution system typology	Associated building insulation level	Inlet/outlet design temperature
High temperature radiator [2]	Poor	80/60 °C
Radiator [3]	Medium	55/45 °C
Low temperature radiator [4]	Good – NZEB-level (net-zero energy building level)	40/30 °C in apartment buildings. 45/35 °C in detached buildings
Floor heating [5]	Good - NZEB	35 °C/30 °C
Air heating based [6]	Poor – Medium - Good	40 - 50 °C/ 30 – 40 °C

In addition to space heating, also domestic hot water (DHW) is supplied at temperature higher than 55 °C through the network. Therefore, if no additional heating is used in buildings, the heat carrier fluid, usually chemically treated water, of the district heating production side needs to reach at least the highest inlet design temperature with a certain margin also. However, the inlet operating temperatures of the indoor heat distribution system are different from the design ones along the year. They vary accordingly to the implemented strategy [7], reaching only in case of severe cold external condition the design values.

A major benefit of District Heating systems is that they can use a wide variety of local energy sources [8] including renewables. For example, waste heat from data centers has been utilized as a heat source of district heating in Finland [9,10]. DHC (District Heating and Cooling) technology platform [11] estimates that in district heating, towards 2020, new types of synergies with sustainable energy sources and production technologies will be adopted, the existing ones significantly extended, and large solar thermal plants increasingly integrated. A Swedish view assesses that the future for district heating lies in a transition towards well insulated, low temperature networks; which will result in lower heat losses and, in time, better conditions for Combined Heat and Power (CHP) production [12].

Finnish district heating, subject of this study, will face new challenges in the near future, since renewable energy production systems are gaining competitiveness on the market, there will be different kinds of waste heat sources available, there is a need to reduce the amount fossils fuels used in producing district heating, and the society is becoming more aware about the consequences of the pollution, expressing the willingness to move towards sustainable and zero carbon lifestyle. Indeed, the EU-imposed energy targets to the member states for the year 2020 [13] and it is willing to increase them for the coming decades. In addition, the 4th district heating generation [1] and new players in the network are approaching: the 4th generation of the district heating network will consist of many energy production systems, including a massive use of decentralized and centralized renewable systems, while the new players, named the prosumers [14], will change the interaction of the buildings with the grids.

The prospects of future district heating in Finland have not been systematically analyzed. This paper aims to fill in the gap by first introducing topics relevant to existing district heating, and then elaborating important current dilemmas, and finally introducing and analyzing district heating concepts, their key supporting technologies and practices. Particularly, this paper discusses the issues relevant for future generation district heating in Finland, looking at the most suitable cases in the World and trying to determine the most interesting and suitable cases to further analyses. The remaining sections of the paper are organised as follows. Chapter 2 present relevant background data and information on district heating and solar potential in Finland, and describes the Finnish building typology. Chapter 3 discusses motivation for next generation district heating. Chapter 4 introduces district heating concepts, as well as enabling supporting technologies and practices. Chapter 5 discusses limitations and aspects, which could be further analysed for a Finnish context. Instead, chapter 6 draws the conclusions of the work, giving directions to future research.

2. BACKGROUNDS FROM FINLAND

2.1. District heating in Finland

According to Statistics Finland [15], the total heating energy consumption of the Finnish residential building stock was 58,480 GWh in 2012. The corresponding energy sources are shown in Figure 1~~Figure 1~~ indicating that 33% of the residential buildings are connected to district heating. The average price of district heating was 74.34 €/MWh for detached houses during the whole year 2012, and 64.97 €/MWh in January and 65.01 €/MWh in July for apartment buildings. The number of clients connected to the district heating has been increasing steadily from the 1970s, but the specific heat consumption in district heated buildings has decreased from about 255 kWh/m^2,a to about 125 kWh/m^2,a [16].

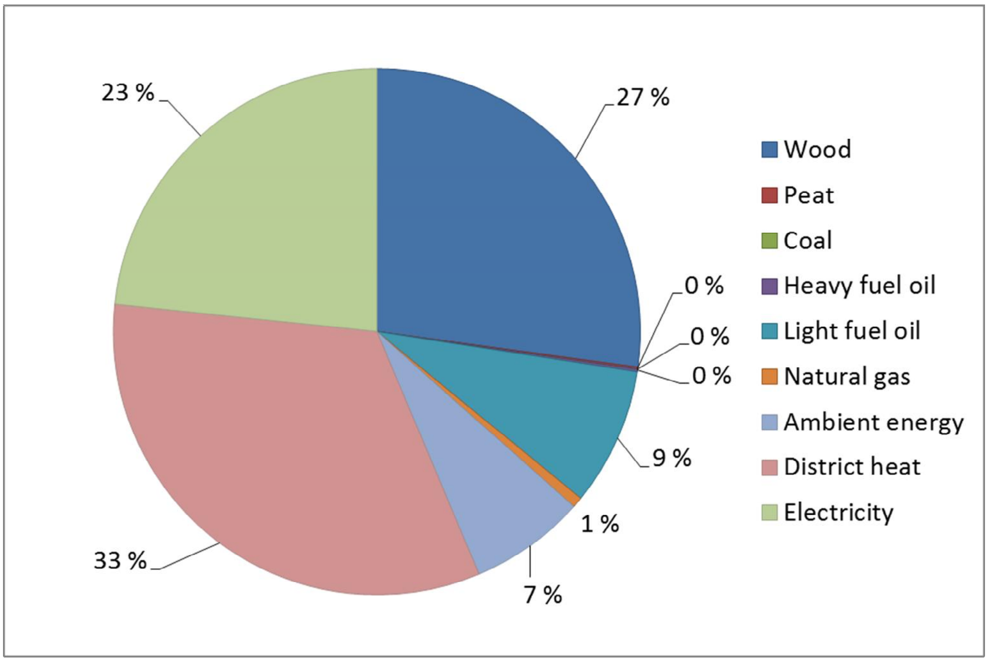

Figure 1. Heating energy sources of Finnish residential buildings in 2012 [15]**.**

According to the Energy Year 2012 [17], the net production of district heat was 38,137 GWh of which 51% was consumed in residential buildings, 9% in industrial buildings, 32% by other consumers, and 8% accounted for network and measuring losses. The total district heat consumption in 2012 was 35,236 GWh. 30.6% of the net production was produced in district heating plants (heat-only plants) and 69.4% in combined heat and power (CHP). In 2012 [17], the most common sources of district heat were: wood residues and forest chip (25%), coal and natural gas (both 23%), and peat (17%). Figure 2 shows the fuel mixes for electricity and district heat produced in CHP and for district heat in separate production in 2012 [15]. There are major differences in fuel mixes between CHP and separate production of heat, especially for oil, hard coal, natural gas, peat, and wood fuels. For example, in CHP only 1% of the heat was produced out of oil whereas in separate production 17% was produced from oil.

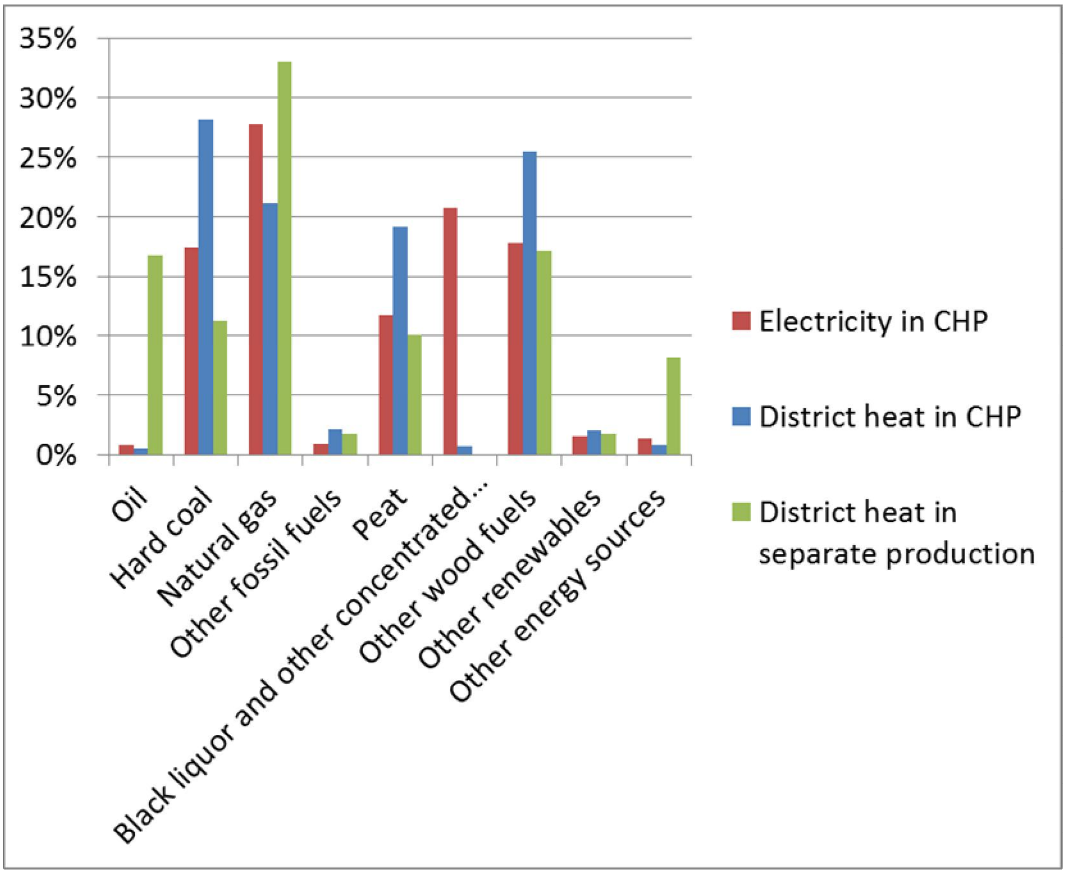

Figure 2. Fuel mixes for electricity and district heat produced in CHP and for district heat in separate production in 2012 [15]**.**

In Finland, there are design requirements and guidelines defined for district heating of buildings [18]. For example, heat exchanger design water temperatures are defined both for new construction and for system renewal in existing buildings. In case the requirements in new constructions would lead to unreasonable problems in radiator sizing, values between 45ºC – 60ºC can be used for the secondary side design temperature. In existing buildings, the design temperatures are based on measured temperatures but should follow predefined values. No temperature requirements are defined for system operation.

2.2. Solar potential in Finland

Comparing the data from Joint Research Centre [19] it can be understood that the yearly sum of global irradiation in Finland does not vary much from Central European countries, especially in the Southern, and more crowded, parts of Finland. Still Finland is one of the few countries in the EU that has taken hardly any direct subsidies into use for solar energy [20] and where the utilization rate of solar energy is quite low. In 2012, only about 14 GWh of solar heat and about 5.5 GWh of solar power were produced in Finland [17].

According to some opinions [21], in Finland, centralized production may offer a more cost-efficient solution to generate solar heat into the district heating network than de-centralized production even though the price level of solar heat is still clearly above the average energy price. On the other hand, Finnish CHP systems are efficient and variable cost of district heat is therefore low in most regions [22].

2.3. The Finnish building typology

At the end of 2013, there were somewhat less than 1.5 million buildings with total gross floor area of 455 million m^2 [15]. 1.1 million of them were detached houses representing 76% of the number of buildings. However, the detached houses (referring to single-family houses) formed only 34.7% of the total building gross floor area (Figure 3). There were approximately 58,000 blocks of flats (referring to multi-family apartment buildings) representing only 3.9% of the number of buildings but forming 20.6% of the total building gross floor area. The industrial buildings accounted for the third biggest share of the total gross floor area with the share of 10.6%.

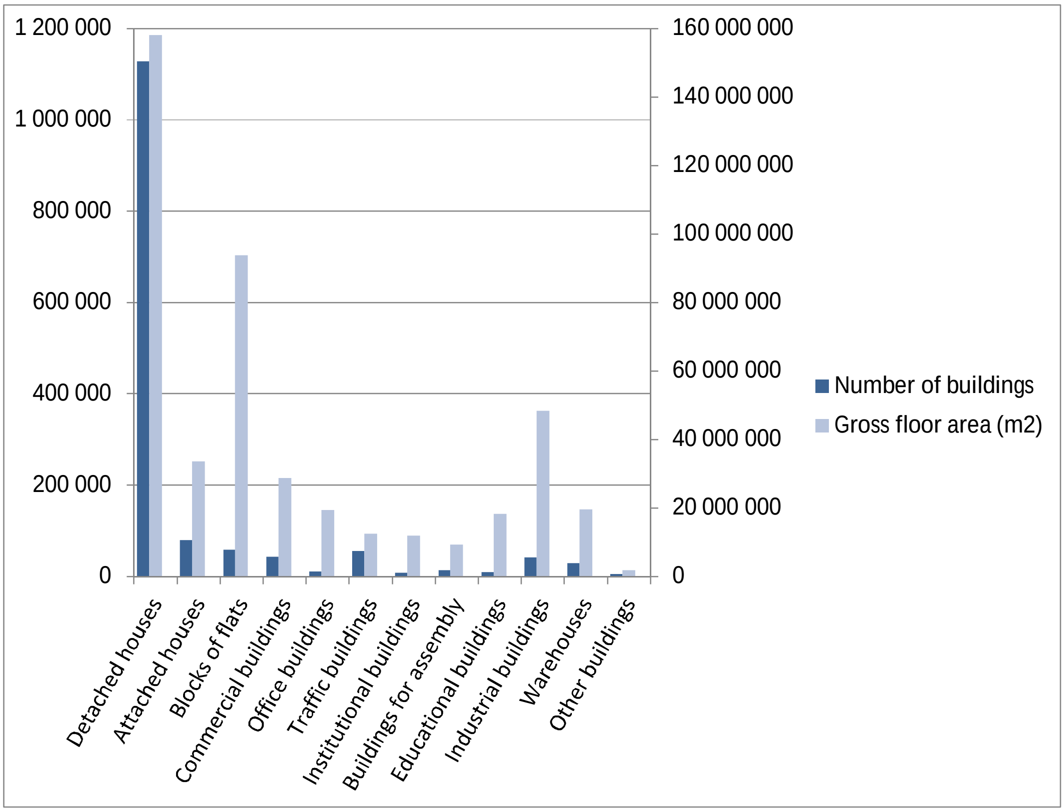

Figure 3. The Finnish building stock as of 31.12.2013 as number of buildings on the left and gross floor area in m^2 on the right [15]**.**

Figure 4~~Figure 4~~ shows the Finnish apartment buildings by the end of the construction year 2013. The number of buildings is shown on the left and the equivalent gross floor area on the right. As it can be seen, the majority of the apartment buildings have been built in the 1970s and are in need or will in the coming years be in need for major renovations. In 2013, 77.4% of the apartment buildings were connected to district heating [15].

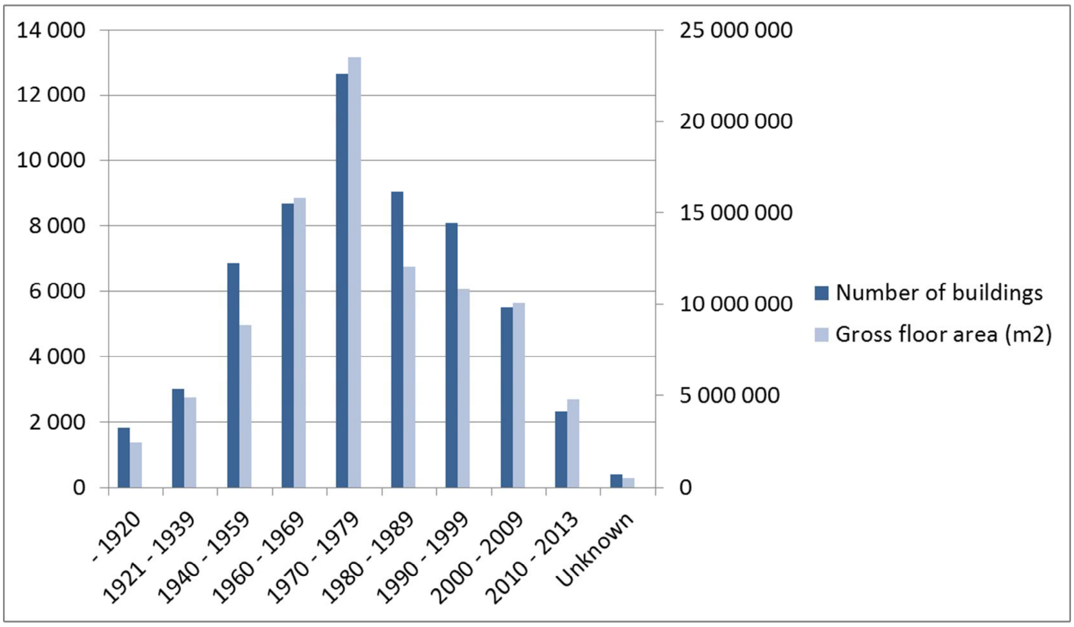

Figure 4. Finnish apartment buildings by the year of construction [15]**.**

The allowable maximum U-values for different main building components according to the year of updated legislation are given in Table 2~~Table 2~~. Often the realized values met the maximum at the time of the construction. It can be seen that the U-value requirements have evolved significantly during the last decades and that the current ones are already relatively low.

Table 2. The maximum U-values (W/m^{2}K) for different main building components in the Finnish building codes [23,24]**.**

Building component	**1969**	**1976**	**1978**	**1985**	**2003**	**2007**	**2010**
External wall	0.41-0.93	0.4	0.29	0.28	0.25	0.24	0.17
Floor	0.35-0.47	0.4	0.4	0.36	0.25	0.19	0.16
Roof	0.35-0.47	0.35	0.23	0.22	0.16	0.15	0.09
Window	2.44-3.14	2.1	2.1	2.1	1.4	1.4	1.0
External door	-	-	-	-	1.4	1.4	1.0

3. MOTIVATION FOR NEXT GENERATION DISTRICT HEATING

The Directive 2010/31/EU [13] imposes that by the year 2020, both European greenhouse gas emissions and energy consumption should be decreased by 20%, implementing renewable energy sources of a share of 20%. Moreover, all the new building should be nearly zero-energy buildings. This raises new challenges in the European building sector, which is now going through a delicate transitional phase towards more energy efficient buildings, such as low energy buildings and passive houses. One of the first measures at the European level, which gave the start of the process of improving the energy efficiency of buildings, was the energy performance of building directive (EPBD) recast (EN 15603). It is obvious that these aspects imply big challenges for the district heating, especially in Finland where many building are hooked up to it (for more information please refer to section 2.3). Moreover, renewable technologies, particularly solar thermal solutions, are now mature to be implemented into the district heating network, as successfully demonstrated in many other Nordic countries and localities [25]. These three issues are elaborated in the following subsections with a special focus on the targeted country.

3.1. Nearly zero energy buildings and districts

Low-energy buildings have significantly lower energy demand, typically 25-50% less, than conventional buildings only meeting the mandatory building regulations [26]. National definitions for very low-energy buildings exist in Finland as well [27]. Especially, Finnish definition of passive house is based on three characteristics: heating energy demand of spaces, total primary energy need of the building, and measured air tightness [28]. Table 3~~Table 3~~ resumes the Finnish passive house definitions for different parts of the country.

Table 3. The Finnish passive house definition [28]**.**

	Coastal area including major cities (Helsinki, Espoo, Vantaa & Turku)	**Central Finland**	**North-East Finland + Lapland**
Heating energy demand of spaces (kWh/m^2)	≤ 20	≤ 25	≤ 30
Primary energy demand (kWh/m^2)	≤ 130	≤ 135	≤ 140
Measured air tightness (1/h)	0.6	0.6	0.6

Requirements for low-energy buildings are often layered with the net-zero energy or carbon strategies [29]. However, there is no established and clear definition of a zero energy building (ZEB) (e.g., [30–34]). Often it has been referred to another term to identify such very efficient energy building: net zero energy buildings (nZEBs) (e.g., [29,35]). In general, it is understood that an nZEB produces as much energy as it consumes throughout the year. Net ZEBs have a dual role of being energy producers and consumers ("prosumers") [14]. In addition to the terminology used, also the energy balance and calculation methods differ for nZEBs [36].

Quite a lot of solutions for nZEBs have been suggested and analyzed (e.g., [37–40]) but only a few have been realized (e.g., [32,35,41]). This may indicate major challenges in realization, such as high costs or complicated system solutions. Anyway, the suggested building level system concepts include more building service systems than what is typical for existing (apartment) buildings. The more systems there are, the more complex operation and management system is needed. Certainly, this requires new skills and may increase the probability of system malfunctions and faults. These barriers are diminished if rather than nZEBs net-zero energy districts (nZEDs) will be realized, as confirmed by [42]. In addition, he has stated that nearly zero energy districts (nZED) can effectively overcome also physical boundary limitations, which represent the main concerns in the refurbishment process of existing buildings towards the nearly zero level, such as access to on-site renewable energy generation. Moreover, the most used renewable technologies to achieve zero energy districts are: PV, solar thermal, air- and ground-source heat pumps, geothermal, and heat recovery [42]. Of course a very important aspect in designing nZEDs is to properly select the district boundaries. Most probably on-site renewable energy production systems will be massively adopted in the district network in order to reach the energy zero district targets. This will create new challenges for the district heating network, which need to be tackled.

3.2. Decreasing building heating loads

A recent study of D'Agostino [42] shows that following the directive, several mitigations measures have been adopted by the European countries. Indeed, some progresses have been achieved by many Member States compared to the very first attempts of establishing nZEBs definitions. In particular, Member States have submitted plans referring to new and retrofit, private and public, residential and non-residential buildings in their definitions of nZEB. These plans mostly refer to demand/generation (including renewable energy production technologies) as an energy balance, performed over a year using conditioned area as normalization factor. It has to be said that, single building or building unit are the most frequent indicated physical boundary of this balance, instead, as regard renewable energy sources, on-site analysis are often considered. Hence, in the near future the number of very efficient and passive buildings will increase, creating very miscellaneous loads of the district heating demand side. Moreover, since retrofitting of the existing buildings will take place, the heating demand of the district heating network will probably decrease leaving room for new buildings to join the network.

It is worth to notice that reducing the heating demand in district heating network goes against the effectiveness of the district heating production side, which depends upon the heat consumption density of the district heating demand [43]. The energy savings of the demand side of the district heating network, where combined heat and power plants are used, reduce the profitability of electricity-based cogeneration production [44]. The district heating supply cost, which is related to the annualized average district heating connection costs, fuel costs and CO_2 costs, is affected also by the heating demand. In particular accordingly to the price of the fuels used in the district heating production side, they can be higher, or in some case about the same level, than the costs of heat demand reduction measures [45]. On the other hand, reducing the heat demand of buildings enables the use of low temperature indoor distribution (design temperature difference from 45/35 °C to 35/30 °C, Table 1~~Table 1~~), facilitating the introduction of, solar thermal heating systems, large scale heat pumps within the district heating network and therefore, boosting the transformation process towards nZEDs. These systems, applied in a district heating network with CHP plants (heat-based cogeneration), may increase the flexibility of the electricity network to integrate the fluctuating renewable electricity energy, such as PV and wind power [46].

3.3. Increasing the efficiency of district heating

In the near future the district heating efficiency is expected to rise for mainly two reasons: the decrement of the supply temperature [1] and the introduction of renewable energy production technologies, which will boost the implementation of nZED [42]. A Danish study [47] shows that low-energy DH systems are promising solutions, when assessing cost-effective and reliable solutions for supplying the heating demand of energy-efficient areas. As stated before, the reduction of the supply temperature will speed up the integration of renewable energy production technologies onto the district heating production side. On the other hand, the indoor distribution systems of buildings, which require from medium to high temperatures (Table 1~~Table 1~~), need to be replaced with low-temperature systems. This renovation measure will take some time, since many buildings have old indoor distribution systems and a consistent investment and mitigation measures are needed. Indeed, to adopt such low indoor distribution system also the envelope of the building has to be renovated, increasing its energy performance. Many recent studies have addressed these aspects for Northern European countries [48–51]. In particular, in Nordic countries policy instruments are needed to support market formation for full service energy renovation, meaning the adaptation of energy-efficient windows and doors, heat pumps, internal extra insulation or new insulation, and advanced heating system [48].

It is clear that lowering the temperature of the district production side will take time as well. However, measures to enhance the efficiency of the district network can still be adopted. These will mostly affect the district heating production side. A recent successful procedure is to install solar thermal system in the production side [46,52–62]. A fundamental role, when solar thermal collectors are used, is played by the thermal energy storage. However, the adoption of the optimized distributed solar energy system allows reducing significantly both the energy supply annual cost and the primary energy consumption [54]. Moreover, a careful planning, design and supervision of such advanced district production side systems is needed to ensure the effectiveness of the system [58].

Nielsen and Möller [60] evaluate the possibility to add the excess heat production from the solar collectors installed in the NZEBs to an existing Danish district heating network, stressing the effect on the district heating demand side between the solar thermal energy on-nZEBs side production and the collective solar production: solar thermal plants on a field of land. It has been stated that if large amounts of solar thermal production systems have not been installed onto the district heating production side, the solar thermal energy NZEBs excess production is useful in the district heating system. The only exceptions to this would be if there is a significant use of industrial waste heat or heat produced from waste incineration. Instead, in district heating network where collective solar thermal covers the heat demand during summer, a seasonal storage for increasing the share of usable solar thermal production from NZEBs is required.

Recently a new player in the district heating network has been defined, the so-called prosumer. The prosumers are located in both production and demand side of the district heating network and can both produce and consume district heating energy [53]. Particularly, the decentralized district heating production in terms of solar collectors and heat pumps has been assessed in an existing Swedish district heating network, emphasizing the role of the indoor distribution system and unbalances in the supply line fluid speed when prosumers are producing feeding energy to the network. Simulations are usually used to perform different energy scenarios assessments and planning the new district heating configuration. However, Brand et al. [53] highlight that the simulation results can be subject to uncertainties, since the customers' district heat consumption has been controlled matching the heat power generation and the demand. Instead, the real operation of a district heating network is often controlled through supply and return temperatures.

4. DISTRICT HEATING CONCEPTS, ENABLING SUPPORTING TECHNOLOGIES AND PRACTICES

This chapter concentrates on the important aspects related to next generation district heating concepts, mainly solar assisted, both on the building and on the district levels. Figure 5~~Figure 5~~ depicts a possible configuration of a Finnish district heating in the near future, where energy efficient and not efficient buildings stand. Two new technologies can be identified: solar thermal collectors and exhaust air heat pump. These accordingly to the implemented strategy can assist the network to supply energy.

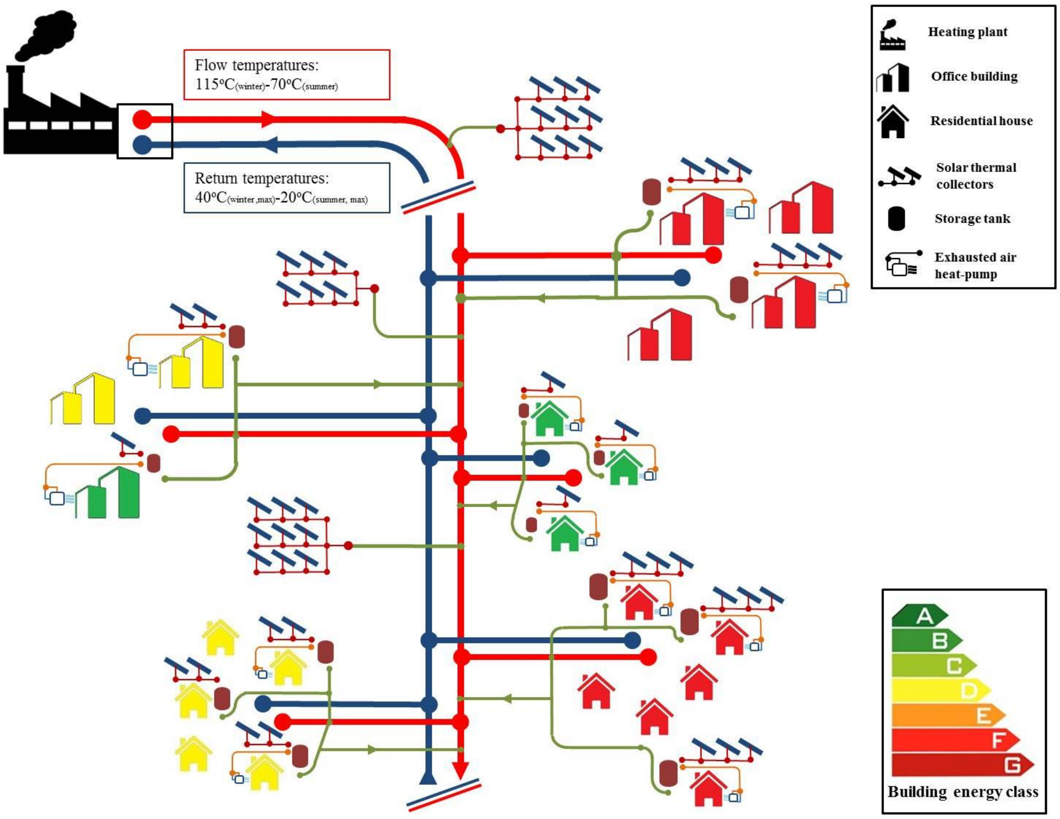

Figure 5. Solar assisted district heating concept with different kinds of prosumers and energy producers. Note: the depicted energy production technologies are only indicative, many other technologies can be considered per each specific location. Note: Building energy class is only indicative of the different energy consumption of buildings

In a solar assisted district heating network, there can be different kinds of prosumers and also independent heat producers (Figure 5~~Figure 5~~). It needs to be carefully considered where these prosumers and heat producers are located in the network and how they should be connected to the network. According to a German case analysis by Ben Hassine and Eicker [56], more than 10% savings in heat loss and pumping distribution energy can be obtained, if consumers with high demand are situated closer to the power plant. If existing district heating systems are complemented with new systems, working at lower temperatures, it is recommended to separate areas with different distribution temperatures in order to facilitate operation [63]. However, particular attention needs to be paid when connecting areas, where the distribution temperature is low, to the main supply

DH line. Indeed, a low-temperature heat connection on the primary line may reduce locally the supply line temperature too much especially in certain network structures [64] and, thus, lead to DH carrier fluid speed unbalances [53]. Despite the aforementioned technical challenges, the main technologies, which will potentially transform in the near future the current energy hungry district heating configuration in more environmental friendly energy infrastructure, are be described in the next section. Authors have also focused on the DH operation and the heat trading mechanism, which will potentially boost the adoption of renewable technologies and the conversion of buildings into prosumer, in order to give a comprehensive picture of DH.

4.1. Solar thermal collectors

There are many solar thermal collector technologies available on the market for buildings end-uses. The choice of the collector typology is driven by the desired working temperature. Figure 6~~Figure 6~~ shows the working temperature of the conventional solar thermal collectors for building end-uses.

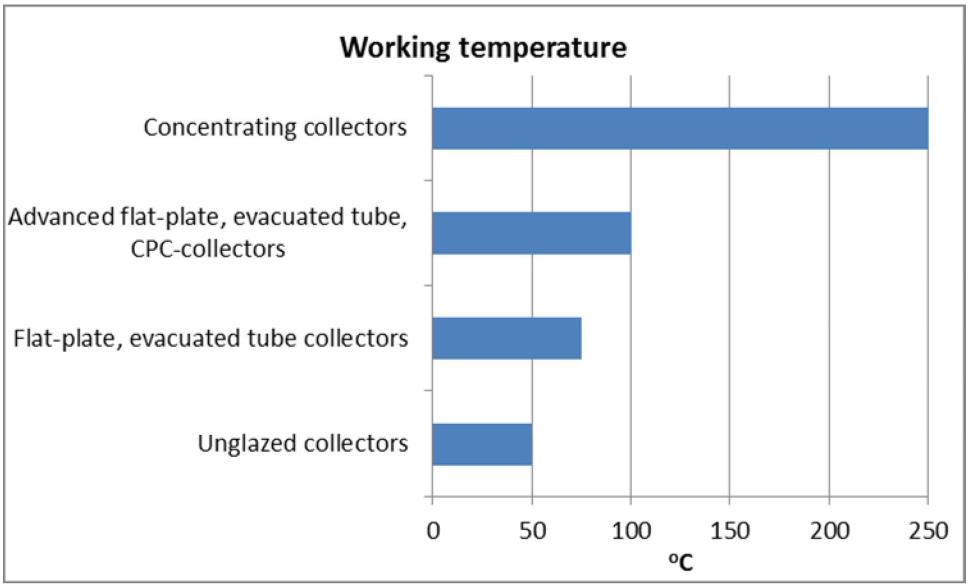

Figure 6. Solar collectors working temperature [65]**.**

Usually unglazed collectors are used mainly for swimming pool heating, while conventional and advanced flat plate or evacuated tube and CPC-collectors (Compound Parabolic Concentrator) for space heating and DHW. It has to be said that advanced evacuated tubular collectors and flat plate collectors are the most common collector typologies for district heating application. Instead, concentrating collectors are not suitable for such application, since they cannot use properly the diffuse irradiation [54]. Moreover, both flat plate and evacuated tube collectors typologies have been installed in existing successful solar district heating systems [52,53]. It is also possible that a large solar heating system includes both solar collector types since they have different advantages and the total cost is similar [53]. Ben Hassine and Eicker [56] introduce four different options to integrate solar collectors to an existing district heating network:

- The SS-assisted network (from a supply pipe into a supply pipe)
- The RR-assisted network (from a return pipe into a return pipe)
- The RS-assisted network (from a return pipe into a supply pipe)

- The SR-assisted network (from a supply pipe into a return pipe)

The SR-assisted configuration is less interesting, since water temperature increase is intended through the collector integration and collector efficiency is estimated to be too low [56]. The RR-assisted option was found energetically the most effective strategy to integrate the existing solar thermal collectors into the considered network.

The RS-assisted concept is the most challenging one from a hydraulic point of view since an additional pump is necessary to overcome the pressure difference between both lines [57]. However, heating grid operators prefer this principle, as there is no change in return temperature and part of the pumping costs is covered by the operator of solar collectors [66]. Generally it is not recommended to integrate solar heat to the return pipe. In case a flue gas scrubber is included in the district heating plant this should be highly avoided [21,67].

4.2. Thermal storage

Two thermal storage categories can be identified: short and long term. The first ones are already implemented in CHP-based DH to shave energy consumption peaks and to decrease the energy generation fluctuations, consequently increasing the efficiency of whole network [68]. Many applications have been already assessed when they are coupled with renewable systems, including solar. Although Kannari [69] estimated that it is possible to produce round 10% of the yearly heat demand with solar collector field without heat storage in a small district heating network in Finland, when storing heat is handled with varying supply water temperature, the use of a thermal energy storage system is extremely recommended to increase the flexibility of an energy system [70] and for solving the time-discrepancy problem of solar energy utilisation; for instance seasonal/long-term storage is a key technology for space heating and can significantly increase the solar fraction [71]. Energy storage systems should be used in order to maximize and use effectively the solar thermal energy. Indeed, the stored solar thermal energy can be used to cover the peaks of the thermal demand in winter and in the transitional months, while in summer the solar system can even cover the whole thermal demand of the district [55], if the solar system is properly designed.

The combination of central solar heating plants with seasonal heat storage enables high solar fractions of 50% and more [52], even in the Nordic climates. In Drake Landing Solar Community in Canada, the solar fraction of 97% was detected in the fifth operation year with a solar thermal system with borehole seasonal storage to supply space heating to 52 detached energy-efficient homes through a district heating network [61].

Sensible heat storage (including water-based storage systems, rock beds, and ground and soil storage) has been demonstrated even in large-scale district heating plants, while latent and chemical heat storage systems remain in the laboratory study stages [71,72]. However, some promising results about thermochemical sorption energy storage for seasonal storage of solar thermal energy have been achieved indicating higher energy storage density and little heat losses [73].

Examples from Germany indicate that the optimum storage concept has to be chosen individually according to local ground conditions and application when seasonal heat storage is combined to central solar (district) heating plants [52]. However, construction costs and thermal losses are still too high for tank and pit thermal energy storages, and the annual storage utilization factor needs to be increased for borehole and aquifer thermal energy storages [52].

DH systems with combined heat and power have additional benefits from short-term thermal energy storages. The electrical power generation can be decoupled from the heat load in the DH system, and thus, electricity can be generated when the electrical price is high and the heat can be stored and utilized when it is best needed. The situation is similar for DH systems, which generate heat using heat pumps. With access to short-term thermal energy storage, the heat pumps can generate heat when the electrical price is low and then supply the heat to consumers when best needed later. Using these two strategies, DH systems can act as a balancing force for the electrical grid. The benefits from such systems will increase with expansion of solar and wind power, leading to larger variations in the electrical price. Indeed, thermal energy storages will be used more intensively in the future with a more fluctuating CHP load and a higher share of renewable energy sources [74]. It might even become beneficial to use electrical boilers in DH systems to balance temporary grid electricity excess [75].

4.3. District heating operation

From the building operation point of view, district heating network provides heat, i.e. hot water in certain temperature and flow rate. From the network operation point of view, buildings have different heat demands which the network has to fulfil in all conditions. The district heating company may use various fuels both in combined heat and power (CHP) plants and in heat-only boilers as well as separately integrate renewable energy sources to the network. The plants and the fuels used for heat production have crucial importance for the environmental impact from district heat use [76]. Production of district heating can be based for example on cost-optimisation or minimising harmful emissions (e.g., [77]).

The current operation control strategy of the district heating production side mainly depends on the prices of the fuels used, the electricity price, since CHP systems are adopted, and the specific heating demand. Particularly, the electricity and the fuels prices, which vary along the day, drive the heat production of the CHP plants as well as heat pumps and boilers. It has to be said that diurnal and long-term electricity price variations are uncertain since several factors such as oil price, outdoor temperature, water reserves and nuclear power availability might all affect electricity price levels [76] as well as wind speed and solar irradiance levels. According to a Swedish study, usually when the price of the electricity is high, during the winter, the heat and electricity co-production in CHP plants is promoted, while low electricity price levels lead to an extended use of heat pumps, hampering the use of CHP technologies [76].

Thus for a particular heating demand to be covered, the technologies able to produce the required heating energy demand at the lowest price are put in operation. Although fossil fuel burners are the most expensive systems to operate, they are committed to cover the daily peak of the heating demand, since they represent the only effective solution to overcome the problems of producing heat during the frequent variations in the magnitude of the heating demand [78]. As regard the CHP technologies, the fuel mix has a significant impact on the cost of electricity, since it affects the economic value of the heat produced by the plant [79].

The demand and supply sides and their interaction should be analysed to improve the primary energy efficiency of district-heated buildings [80]. In addition, a reduced heat demand due to high energy efficiency in buildings might hamper co-production of electricity and district heating [81]. These examples emphasise that the whole energy chain should be analysed in order to avoid undesirable effects in some parts of the energy production.

If daily heat load variations, being 3–6% of annual heat supply in Swedish district heating systems, could be eliminated in district heating systems, it would make the operation of the district heating system less costly and more competitive [82]. An Italian study shows that the minimum value of the average useful heat costs is achieved when co-generators, district heating network, solar field and heat storage are all included in the energy supply system and optimized [54].

4.4. Heat trading

The idea of heat trading is not new, but only now when small-scale heat production has become more common it has arisen again. Liberated heat trade can be carried out by the same principle in local district heating network as electricity trade [83]. A small-scale producer can sell heat to customer(s) through the local DH-network. A network operator takes in the heat from a small-scale producer and gives out the heat to the customer. The network operator keeps up the temperature and pressure in the DH-network.

Bröckl et al. [64] found out that, on one hand, the interest of Finnish district heating companies for buying excess heat from industry is clearly higher than for acquiring heat from small-scale production; on the other hand, customers want to sell heat if the required investments can be covered in a reasonably short period of time. In order to make heat trading possible the district heating networks need to be opened which is not the case in Finland at the moment. In Sweden in the similar climate as Finland, the Stockholm city has opened its district heating network for all heat suppliers [84].

5. DISCUSSION

A new player will probably show up in the district heating network. This is the prosumer, which is a building that consumes and produces energy; the produced energy can be consumed on-site or delivered to the district heating network. This new figure can potentially boost the introduction of renewables into the district heating network. However, both prosumers and renewable centralized systems need a tailored financial model to attract private small, medium and big investors. The financial aspects are not taken into account here, but the work focused only on the energy aspects of the network and building operations of a possible future Finnish district heating network. This step is fundamental to create a consistent basis for economic and financial analyses. It is worth to mention that prosumers may also affect the pipe dimensioning [12,53], which was not analyzed in this paper either. However, heat suppliers should be careful with oversizing a network, since unnecessarily large pipe diameters result in larger heat loss and higher investment costs [85].

It should be noticed that often issues have multiple effects and it is not necessarily straightforward to select the optimum alternatives neither for the system design solutions nor for their operation. For example, if other than CO_2 emissions were considered when analyzing energy production solutions for a Russian district heated residential area there would be no easy answer as to which energy production scenario would be the best one [86]. It can be estimated that similar conclusions can be drawn from other cases and countries as well.

When designing energy systems and mixing different energy sources, energy security should be also taken into consideration [87]. This was not within the scope of this research. An example from Germany show that for the reliability of electricity supply it could be reasonable to use electric boilers in district heating grids if high shares of renewable energy sources are utilized [88].

One of the dilemmas of the paper was the decreasing building heating loads. However, it should be noticed that in the future, building electricity loads may increase which especially in the summer time can lead to increased cooling demands. At the moment, Finnish residential buildings do not typically include cooling systems. However due to the fact that residential buildings are becoming more insulated and office buildings already have cooling requirements, cooling energy can be effectively produced using decentralized chiller driven by district heating and solar heat also in Finland [89].

It is important to notice that in order to carry out detailed energy assessments of district energy solutions, simulation based approach is often used, simplifying the actual district heating network structure [90].

Moreover, business model are very fundamental to lead new developments. Particularly, the essence of a business model is in defining the manner by which the enterprise delivers value to its customers, entices its customers to pay for value, and converts those payments into profit [91]. According to Osterwalder [92], a business model is a conceptual tool that contains a set of elements and their relationships and enables the expression of a company's logic of earning money. One key issue to boost the transition toward the future district heating generation in Finland is the business model(s) to adopt. This needs to be carefully generated and assessed in future research.

6. CONCLUSIONS

Over 30% of Finnish residential buildings are connected district heating. Meeting the requirements for nearly zero energy buildings, decreasing building heating loads, and increasing the efficiency of district heating are core dilemmas which future district heating will soon face in Finland and which were analyzed in this paper. Table 4 shows the key properties of existing and future district heating in Finland which this paper covered.

Table 4. Key properties of existing and future district heating in Finland.

Existing district heating	**Future district heating**
• Strong role of non-renewable energy sources • Based mainly on centralized production • Typically municipal production monopolies • Existing stakeholders • Supply water temperature supporting high- or medium-temperature radiators • Buildings with varying energy efficiency connected to district heating • Traditional technologies • Traditional business models	• Increasing share of renewable energy sources • Enabling trigeneration (production of electricity, heating and cooling energy) • Increasing share of distributed and local production • Networks opened for all heat suppliers • Introducing prosumers • Supply water temperature supporting low-temperature heating • Increasing share of nearly zero-energy buildings connected to district heating • Utilization of supportive technologies • New business models

In addition to the prosumer figure, the most promising technologies and their related operations have been described, particularly stressing the most suitable for a possible integration onto the Finnish district heating system. Especially, the renewable technologies that could be further analyzed in this context are:

- solar thermal collectors: Evacuated tubes and flat plate collectors (only single technology or a mix of both),
- thermal heat storage: short-term at the building level, long-term at the district level,
- heat pumps (especially ground source heat pump seems to be very effective in Nordic countries, e.g. [93]).

These technologies could be analyzed at the building level, as three different prosumer typologies:

- prosumer 1: building with solar thermal collectors and short-term thermal storage
- prosumer 2: building with short-term thermal storage
- prosumer 3: building with ground source heat pump and short-term thermal storage.

At the district level, long-term thermal storages, solar thermal collector fields of medium and big sizes and ground-source heat pump of medium and big sizes should be also investigated. Thus, it may be of interest to analyze the following three cases; all will refer to an existing Finnish network. The first would be the reference case, emulating the current operations of the district heating network. In the second case only different prosumer typologies would be considered, while in the third case district level systems would be added. Obviously both second and third case should be compared to the first case to understand the potential, in terms of energy performance, of the renewable systems, in general, the impacts of the prosumers typologies and, more in detail, the effects of the adoption of both prosumers and district renewable systems in an existing Finnish district heating network.

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