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RELaTED, decentralized & renewable Ultra Low Temperature District Heating, concept conversion from traditional district heating

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Abstract. District Heating (DH) are a very efficient system for heating in urban areas and they are considered as key elements for the de-carbonization of the European Cities. High performance levels and low operational energy costs are part of the identity of these heating networks. The reduction of supply-line temperatures allows the possibility to introduce new low-grade and renewable source energy production, reducing dependence on fossil fuel-based energy plants. Moreover, heat-losses in distribution pipelines are also reduced, since the gradient temperature between supply line and ambient temperature is reduced. Operation of decentralized & Ultra Low Temperature (ULT) systems may adapt for the introduction of weather-dependent, distributed heat sources such as solar systems. Furthermore, although very dependent on local availability, waste heat streams from commercial and industrial installations are also considered because of the stability of heat supply all year round, resulting in minimally carbon intensive processes .Regarding building features, the reduced heat load derived from the transition from current buildings to Nearly Zero Energy Buildings (NZEB), RELaTED allows for the novel concept called prosumer, where buildings can deliver energy to the grid from decentralized energy sources installed in the building. In RELaTED, different subsystems are being developed by different industrial partners, to prove their efficiency in 4 real demonstration sites: Tartu (Estonia), Belgrade (Serbia), Vinge (Denmark) and Iurreta (Spain). A 3-FS (3-Function Scheme) DH substation that permits buildings to become prosumers. Two types of solar collectors, one is an all polymeric glazed collector and the second one is an unglazed collector, both as components of Building Integrated Large Solar Thermal Systems (BILSTS) solar loop. Finally, a reversible and high efficiency heat pump for domestic hot water is being developed. In this paper, an approach to ULT concept is studied, including transitory phases of the conversion.

1. Introduction

District heating (DH) systems are one of the most energy efficient heating systems in urban environments, with proven reliability within many decades already. DH of today and older ones are based on large Combined Heat & Power (CHP) or large Gas boilers reaching supply temperatures near to 100ºC. Today, DH networks cover more than 13% of the total heat demand in the EU, and in the future, this number is expected to grow. Future DH networks must develop other characteristics to reach some targets that makes them feasible. Comparing with actual DH networks, those for the near future must reduce grid losses and they must find synergies that increase efficiency of the whole system.
DHs are identified as key systems to achieve the de-carbonization of heating energy in European Cities. [1]. However, DH networks are still highly dependent on fossil fuels. According to [2], the worldwide DH production is still based on non-renewable sources, with about the 90% of the heat production coming from fossil fuels. In the European Union (EU), the share of fossil fuels is a bit lower, only reaching the 70%.

Renewable and waste heat sources are foreseen at the same time as de-carbonized heat sources and the way to guarantee competitive energy costs with limited influence of fossil fuel supply price

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volatility. To achieve this, a transition is needed in DHs, comprising not only measures to improve overall performance (temperature level reductions, improvement of substations, etc.), but to guarantee system viability as a whole in a context [3] of reduced heat loads with the transition to nZEB (Nearly Zero Energy Buildings). The current situation is that buildings are responsible for around 40% of total energy consumption in the EU [4]. According to [5], the building stock in the EU rounds 150 million dwellings, which more than 70% of them are built before 1980 according to constructive measure of the time. New buildings rate is about 2 million new dwellings per year, so that by 2050, more than 70% of the building stock is already built. So, the steady incorporation of NZEB in districts will be partially limited by old buildings making necessary for DH to find solutions for this combination and not only for nZEB.

Regarding RES (Renewable Energy Source), solar energy is situated as the one with highest potential, divided into Large Solar Thermal (LST) plants with seasonal storage and the distributed solar systems along the DH network. ST energy and heating demands, however have opposing trends, and when the solar irradiation and in fact solar production is high, the heating demand in residential buildings is often low or null. This often makes necessary the installation of daily or seasonal storage in LST, so that the heat generated in moment of overproduction can be used in periods of no solar energy.

Along the last decade, already in several EU locations, large ST systems have been successfully connected to DH networks under commercial operation. Linked to variations of solar resources and electricity costs-for heat pump heating-, over the year, several DH networks have incorporated large scale thermal storage systems [6].

In fact, for some concept districts such as the Drake Landing Solar Community [7], full solar cover of heating loads has been achieved with a mixture of ST and seasonal storage even in cold climates in continental Canada at 50ºN.

Distributed solar energy or as it will be used in this paper, building integrated solar thermal systems (BISTS) are installations located near the consumption point, avoiding distribution heat losses and enabling the direct use of the heat. Most ST systems have been incorporated in roofs [8]. The main reasons for this are that incident solar radiation falls upon directly the roofs of the building, whereas the south façade of a building only receives the 70% [9] of the total radiation. However, in the winter, the south façade receives a greater solar insolation than the roofs due to the low solar height in these months. Moreover, installing ST system on the roofs limits the impact of these systems in the overall building aesthetics.

On the other hand, although very dependent on local availability, waste heat streams from industrial and commercial (e.g. supermarkets) sources, are relatively stable sources of heat. Large scale industrial processes are active all year-round, resulting in minimally carbon intensive processes.

[10] studied the configuration of the DH network in Kiruna, SE, where a large iron mining setting provided a de-carbonised heat recovery source. In all calculations where, industrial waste heat was introduced, the optimal situation made use of the maximum capacity of the industrial waste heat (15MW), it provided. The relative relevance of this heat source was 30% of the winter peak load (49MW) and 38% of the winter average load (39MW).

With unprecedented performance levels in fuel-based heat production processes, improvements in performance levels will only have minimal impact in the route to DH de-carbonisation. The transition will require the large-scale integration of ST systems, and waste heat resources. Linked to load reduction in the progressive transition to NZEB performance levels, with progressive connection of BIST into the DH, a de-carbonised DH environment can be achieved

2. RELaTED conceptualization

RELaTED [1] deploys a novel concept where Ultra-Low temperature (ULT) DH networks are developed. The reduction of supply-line temperature guarantee the incorporation of low-exergy heat sources with minimal constraints. At the same time, it enlarges the renewable energy sources based (RES) heat and a reduction in operational cost due to the reduction of heat losses in distribution pipelines. All this leads to a better overall performance of heat generation plants and extensive use of de-carbonized energy sources at low marginal costs.

In the transition towards NZEB and PEH (plus energy houses), RELaTED allows for a prosumer scheme, where positive buildings deliver energy to the grid.

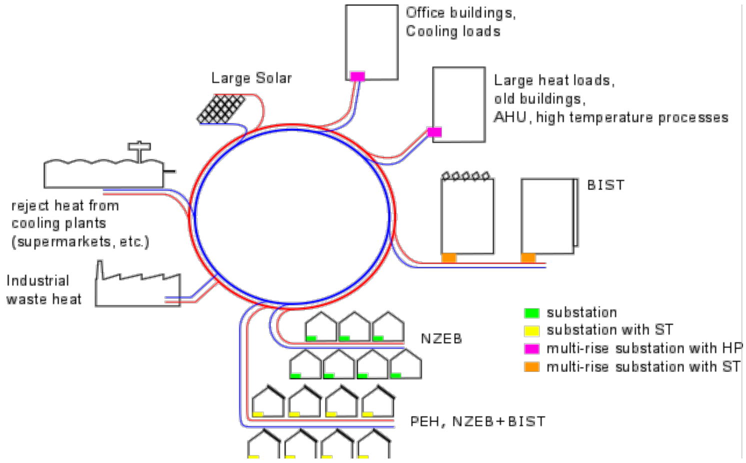

Figure 1. Overall Concept scheme for RELaTED DH networks

Figure 1 shows the overall RELaTED concept for ULT DH. RELaTED builds over existing evidence [10] that DH supply temperatures as low as 45ºC, are suitable for heat supply to define its ULT DH concept.

In RELaTED every single building is converted into an energy node, where so-called triple function substations (3FS) allow for bi-directional heat exchange between the building and the network, with the additional functionality of grid injection of excess local solar heat. In fact, adaptations are made to Building Integrated Solar Thermal (BIST) systems in order to adapt them to Low Temperature (BILTST), with reduced local storage, as the connection to the DH makes it redundant.
Additionally, District-heating connected Reversible Heat Pump systems (DHRHP) allow for recovery of exhaust heat from cooling applications (e.g. air conditioning, ventilation, etc.).

Even before the consideration of further technological improvements, ULT temperature levels substantially improve the performance of heat production systems. It is estimated that CHP performance can be improved by a factor 2 to 5, considering [11].

RELaTED builds atop of the existing trend for integration of large solar thermal plants systems in DH networks, some of them comprising large seasonal storage systems. RELaTED incorporates large ST plants, but also provides the framework for the integration of BIST into the main ULT DH concept. With lower fluid temperature when compared regular BIST integration levels, performance levels are expected to rise by 20%, due to lower heat losses. An additional 20% rise is calculated when avoiding local storage due to direct DH connection. The RELaTED ULT network acting as a perfect heat sink avoids storage stagnation situations, thus allowing for larger ST performance levels.

So, summarizing all above, RELaTED concept is based on the following operative characteristics of a heat network:

- Ultra-Low Temperature (ULT) System (~45ºC) for the supply line. This system can be combined with a micro booster for DHW preparation. This micro booster is located in each of the buildings and allows a temperature rise for the DHW and this way, avoiding the risk for legionella.
- Decentralized or distributed DH network, enabling the connection of smaller heat sources along distribution pipe. The heat production is not only dependent on a unique generation plant and the incorporation of low-grade heat sources is enabled
- Buildings served by the heat grid act as energy nodes, becoming consumers and production plants at the same time. Heat demand is metered and controlled by smart energy meters which allows a better efficiency of the network, avoiding generating excess heat that cannot be after wise used.

- Incorporation of DHRHP, allowing heat-recovering from cooling applications. Heat from condenser in refrigeration cycle, can be used as the heat source in the evaporation process of heating cycle.
- As the main distributed heat source in the system and in combination with traditional LST, BISTS are installed in respective buildings. Solar systems in façade are also considered due to the larger area available in this wall of the building. This way, larger solar fraction is obtained
- Substations allow for bi-directional heat exchange. In the next chapter is presented the design for the triple function substation proposed in RELaTED.

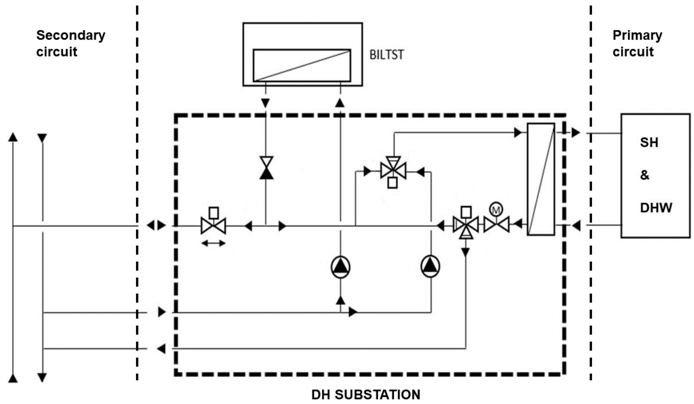

Figure 2. Design of triple function (3FS) substation for RELaTED.

3. DEMO site in RELaTED

Considering the complexity and particularities of a DH network, RELaTED is planned to be implemented in four different DEMO sites. Different conditions are covered by the following 4 sites, including different climatic conditions, constructive traditions or urban densities.

3.1. Belgrade (Serbia)

The existing DH network in Belgrade comprises around 750km of pipelines, delivering annually 3500GWh to around the 50% of the city. Within RELaTED, intervention plan in this network will focus on the installation of various distributed heat sources and the conversion of one of the subnetworks to LT (50-55ºC) levels.

3.2. Vinge (Denmark)

This network will be situated in a new urban development in Vinge, where all the houses of the district will be low energy or passive houses. This site will demonstrate the scalability of the ULT DH concept where grid design should adapt to steady increases in energy loads by connection and diversification of energy sources. ULT (60/30ºC) levels are expected.

3.3. Tartu (Estonia)

DH in Tartu delivers more than 500GWh yearly and is based on the combustion energy obtained from biomass and peat. The district comprises synergies between different type of buildings, including residential, industries, commercial and educational buildings.

3.4. Iurreta (Spain)

The last DEMO is situated in a corporate complex in which the heat demand is covered by a centralized gas boiler system combined with distributed heat pumps.

4. RELaTED in new and existing DH networks

4.1. Implementation into new Districts

The RELaTED ULT DH concept is directly applicable to DHs in the context of new urban developments. In these cases, previous experiences are directly applicable, allowing for SH at 45ºC. Sizing of heating networks in buildings and the overall DH infrastructure would be made according to the expected heating temperature, with standard calculation procedures.

As defined before, DHW loads are key issues, where, electric heating would be applied, either by means of electric boosters or heat pumps (depending on the rated power). [12] tested an electric booster system connected to a DH network at 40ºC. In this experimental work, the use of electricity accounted to 30% of the DHW preparation energy, or 3% of the overall energy consumption.

RELaTED proposes an advanced 3FS substation concept, where local ST systems can be connected into the DH network, and substations allow for LT distribution systems, with the potential use of electric boosters. In some cases, where cooling loads are present or high temperature heating systems are used, DHRHP systems provide an alternative to electric boosters

4.2. Implementation into existing DH networks
Conversion from traditional and fuel based existing DH network to ULT heat network is a complex process, which needs to be performed stepwise. If the service needs to be maintained in the conversion process, supply of SH and DHW must se guaranteed, and if not, auxiliary heat sources must be provided to the customers. In most places, the demand for SH is partially interrupted in summer periods but DHW is required all year round.

In the conversion process, as long as the transitory phases are made, all buildings within a network are equipped with an updated substation, according to the transitory operation conditions. The most limiting operation conditions will be the supply temperature of each subnetwork and the heat transmission in the HEX (Heat Exchanger) of the substation, so that internal comfort is always secured.

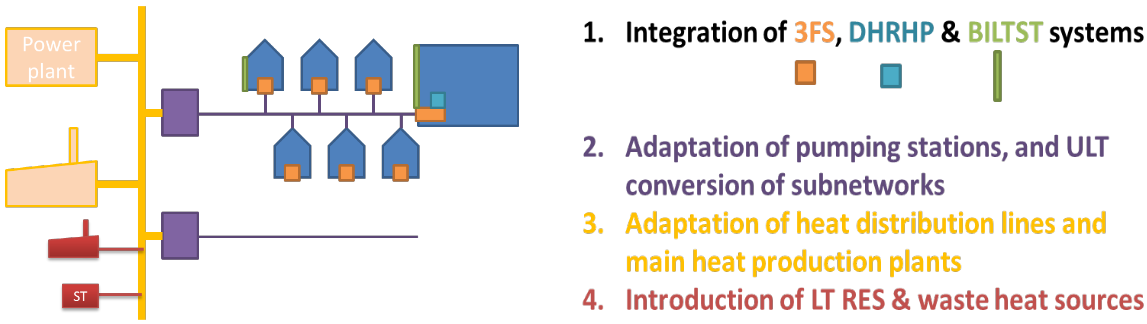

Figure 3. Conversion process from a DH into a ULT

In Figure 3 is shown the possible phases for the conversion of a DH into a RELaTED concept ULT DH. The process begins with the progressive incorporation of substations, heat pumps and BILSTS which involves little modifications to the operation conditions of the network. Then, beginning from the subnetworks, the supply conditions are modified, adapting the impulse flow rate so that conditions in the secondary circuit are not modified. The next step and after verifying the correct service in the buildings, conditions of the mains distribution lines are changed including supply conditions of the main heat plants. This reduction of temperatures will improve the thermal efficiency of main heating plants as well as the distribution losses are reduced. During this process, introduction of RES and heat from waste heat sources, as long as the current temperature ranges are compatible, or at least there is mutual agreement between heat supplier (factory, data-centre etc.) and DH owner.

5. Conclusion
RELaTED is an ongoing research & development, with expected demonstration activities along the 2018-2021 period. The overall ULT concept, integration of 3FS, BILTST & DHRHP subsystems, industrial waste heat, large ST & waste incineration plants will be demonstrated in 4 selected locations:

- Green field development in VINGE, DK
- DH network with large share of biomass in TARTU, EE

- Large DH network with incorporation of large RES resources in BELGRADE, SR
- Corporate DH network in IURRETA, ES

Successful demonstration of RELaTED in this context will show the potentialities of the system under various climatic conditions, heat production mix & DH design/operation cultures.

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