DESIGN OF CONSUMMER THERMAL SUBSTATIONS FOR THE INTEGRATION OF DISTRIBUTED SOLAR TECHNOLOGIES IN DISTRICT HEATING SYSTEMS

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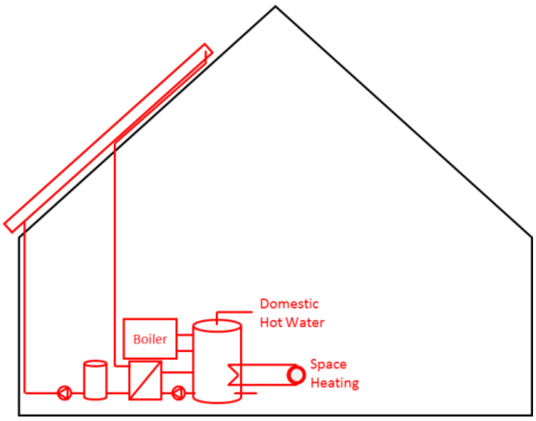
Abstract – In most cases, building service designers choose between Solar thermal (ST) and District Heating (DH) technologies for their integration in buildings. By doing so, only a fraction of the buildings within a particular district is used for ST, while at the same time energy intensity in DH networks can be reduced. In some cases, building-integrated solar thermal systems are connected to DH networks by means of dedicated pipes. In all these cases, sub-optimal situations are reached with lower fraction of renewable heat, reduced network strength and/or additional heat losses.
In this paper, a consummer substation concept is proposed with reversible heat flow and net metering, which avoids local thermal storage in the solar loop. Adaptations required for multi-dwelling buildings are presented.

1. INTRODUCTION

With limited energy resources to meet the requirements of a steadlily increasing population, there is a clear trend towards the implementation of energy efficiency (EE) measures and de-carbonisation of the energy supply for heating applications.

In the EU context, EPBD policies and national regulations require of increasing levels of building energy performance levels and incorporation of Renewable Energy Sources (RES) such as solar thermal (ST) technologies.

In the context of individual buildings, ST systems are composed by a solar collector field, a thermal storage system, and an alternative heat source such as a boiler, which delivers complementary heat during peak consumption periods without solar radiation in winter. Due to techno-economical optimisation, in most common cases, ST technologies are only sized to cope part of the heat load of buildings.



Schematic of Drainback ST system. Auxiliary elements are not represented.

District heating (DH) systems are highly efficient heating systems which have been developed & operated over decades in urban environments. To-date, DH has been supplied mainly by large fossil-fuel fired boilers, or Combined Heat and Power (CHP) systems, although other implementations incorporate waste heat from large industrial settlements, or substitute fossil fuels with biomass.

In the last years, a number of satisfactory experiences have proven the commercial application of large ST plants and Thermal Storage (Werner, 2017). Thses plants act as a substitute for polluting energy production systems. Following these experiences and its potentiality to integrate waste heat streams, DHs are identified as key systems to achieve the de-carbonization of heating energy in European Cities. (European Commission, 2016). RES integration achieves the dual objective of de-carbonization of heat sources and the limitation of heating cost exposure to the volatility of fossil fuel price.
In many areas, the feasibility of installation of centralized ST plants is limited by geographical constraints and scarcity of land in larger cities.

DH configuration has evolved over time in order to adapt to increasing EE needs and variation in heat loads with the modernisation of buildings and their heating systems. Temperature levels have been substantially reduced and substation configuration improved, among other measures.

With an expected switch towards Nearly Zero Energy buildings (NZEB) over the next decades, heat loads to be supplied are expected to reduce substantially, and measures will need to be taken to ensure the economic viability of DH systems.

With an increased share of NZEBs in districts, it is to be expected that heat production in these buildings may frequently exceed local needs in these buildings. DHs should take profit of these heat which would otherwise be wasted. With steady reductions in operational Temperatures in DH, oportunities to do so are increased.

To do so, it is required that subsations at building level are adapted and suitable heat purchase tariffs and net metering are applied.

2. CURRENT DH SUBSTATION CONFIGURATIONS

District heating substations are devices whose main function is the connection of loads to DH networks in a standardized manner. Each DH operator specifies particular considerations regarding design & construction of substations in order to achieve homogeneous service levels within the network.

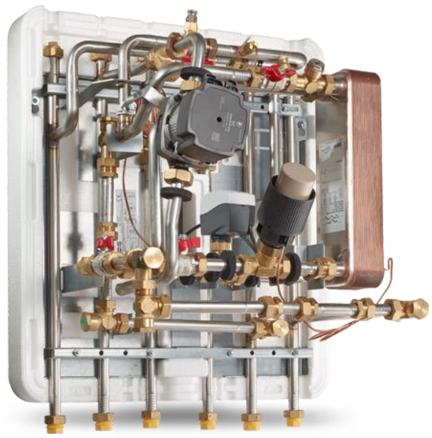
Considering that medium-large DH networks commonly comprise thousands of consumers connected into the DH network (DH network in Belgrade serves CA 1 million inhabitants), industrialized substations have been developed to guarantee common connection criteria with simplified engineering, installation and commissioning works.

In most common applications, substations comprise: several heat exchangers, which serve as a physical barrier to avoid local leakage to cause mayor failure of subnetworks serving; regulation valves & controllers, which serve to ensure standardized return temperature levels in the DH; heat meters, for billing purposes; and auxiliary devices.

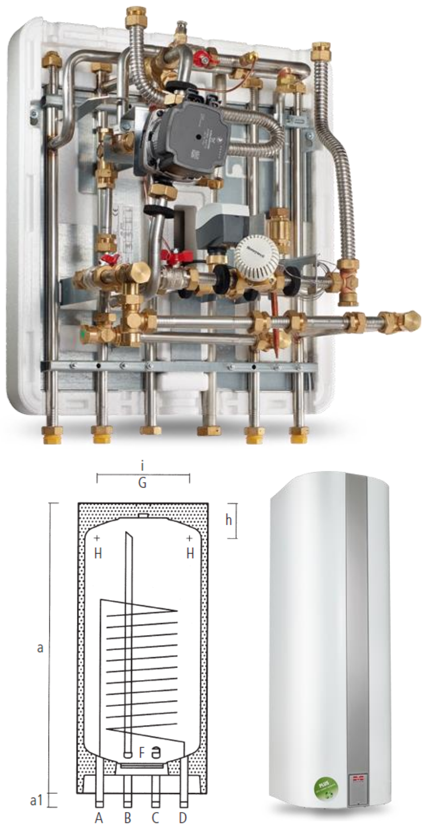
2 common configurations are possible:

- Substation with heat exchanger for space heating and thermal store for DHW preparation. In this configuration, the thermal store is heated by means of an inmersion heat exchanger which de-couples DHW from the DH circuit. This configuration is valid both for individual dwellings but also for centralised heat deliveries within multi-rise buildings.
- Substation with 2 heat exchangers. DHW production requires of substantially larger sizing of the pipework, high quality/capacity heat exchangers and precise instrumentation. Limitations are imposed to the laying of DHW pipework within the building. This configuration commonly applies only to individual housing/apartments.

In multi-rise buildings, the use of centralised DH substations imposes a relatively high service temperature for DHW preparation due to the need to keep DHW storage tanks and pipes at legionella-safe temperature levels.



Appartment Substation for direct space heating and DHW preparation (Source: METRO THERM)



Substation with indirect preparation of DHW, and compatible DHW storage tank (Source: METRO THERM)

When low-temperature DH networks are implemented, substations at dwelling level are commonly selected. In these, lower temperature lossess occur as centralised HVAC plants are avoided, and lower temperature levels are possible due to smaller DHW loads, and the possibility to satisfy these by means of instantaneous heating with heat exchangers.

Modern substations are sized to perform correctly at temperature levels in the viccinity of 55ºC, but lower temperatures are also possible under request, as long as the DHW preparation process is complemented by other means (e.g. electric boilers, heat pumps,…).

In Industrial settings, different types of substations may be possible. These are not analized in this work.

3. DH-CONNECTED ST SYSTEMS

In the last decade, there has been a large boost in the construction and operation of large ST plants, connected to DH networks.

Depending on the size of the system, available ST capacity, etc, large seasonal thermal storage systems have been installed along with these systems.

These systems are not connected to buildings directly, and they are operated by DH operators directly or as independent heat producers. As such, their interconnection schemes are not relevant in terms of substation definition for de-centralised ST systems. Nevertheless, these setups demonstrate that ST is a viable source of heat in the context of DH networks, and that there should be room for de-centralised ST in systems with limited access to land for large ST installation.

Sources such as (Solar District Heating) show the actual status of the technology.

The recurrent use of thermal storage along with ST technologies in DH clarifies that such storage is critical to get the most of ST systems at DH level, by capturing solar energy during summer months and making it available during winter period. However, for relatively small ST systems, with heat production not exceding heat loads in summer, this storage could be limited to inter-daily needs.

4. DISTRIBUTED, DH-INTEGRATED ST SYSTEMS

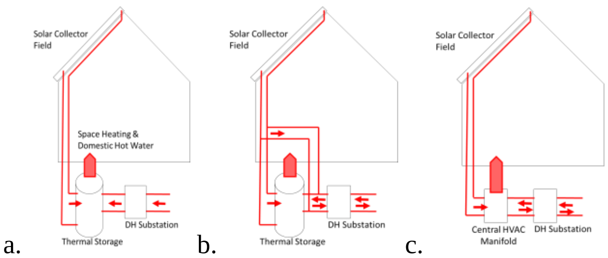
Solutions for the integration of ST systems in buildings have been extensively investigated and demonstrated over decades already. Requirements on minimal solar fractions are imposed in building codes acros Europe, which can even be satisfied by means of off-the-shelf systems. Most common ST solutions incorporate ST collectors, in a presurized circuit, which delivers heat to a stratified storage tank. Auxiliary heating devices-most commonly, natural gas boilers- are incorporated in parallel to meet heating needs in buildings when the solar resource is insufficient. Many reviews on ST systems and case studies can be found in literature such as (Hadorn, 2015)

DH connection of these systems can be performed under various approaches. Following the general interaction scheme expressed above, DH can be used as an alternative heat source for those moments where the ST system is not able to cope with the heat load in the building. In this case, Buildings behave as regular DH connected buildings, but with a reduced heat load during periods with ST heat production. There is no possibility to inject any ST excess heat into the DH network.

However, this approach limits the potentialities for the use of excess ST energy outside the building itself. (Gavalda, and others) studied the potentialities of reconficuration of individual ST installations to deliver excess heat to the DH network in Barcelona, where the surplus energy delivered to the DH reached 50% of the total heat produced. With ST sized for winter use, almost no surplus energy is delivered in winter period, but surplus energy accounting to 1.5-2 times the heat production in january is delivered monthly during the spring, summer and autum periods.

These figures are valid for the case of ST installations operating at its regular temperature (e.g. 60-70ºC of heat delviery temperature.

A further improvement in the interconnection would be such that the ST system is connected to operate at lower temperature -thus higher performance levels. In this context, excess heat is delivered into the return pipe of the DH.



Connectio Schemes of ST systems to DH. a. ST & DH in parallel. b. Delivery of excess heat to DH. c. Hibrid system without ST storage

DH systems are large hydronic sytems. Due to its large capacity, and considering the relatively small share of ST systems connected to the network, DH systems can be considered as an ideal heat sink. Under these circumstances, all heat produced by the ST system, is consummed by final users consummed to the network. Shall ST integration in DH be massive, DH operators should steadily incorporate thermal storage to the network. Anyhow, the cost of large scale thermal storage is substantially smaller to incorporating storage to each ST unit.

Extensive cost reviews of thermal storage for ST systems state that cost can be reduced by a factor 4-6 when large storage sizes & technologies are applied (Mauthner and Herkel). Considering present cost of thermal storage techonlogies for ST systems, DH connected systems could easily reduce their present cost by 50-100€/m^2. As stated before, these cost would only be partially transferred to the DH operator for situations with large fractions of ST integrated in the district.

5. POTENTIALITIES OF DH-INTEGRATED ST SYSTEMS

DH connection of distributed ST systems provides several advantages over insulated ST systems.

From the Energy point of view, the yearly solar energy yield is substantially increased. (Gavalda and others) states that with DH-connected ST, yearly heat production in the range of 654 kWh/m2 are possible. This figure almost doubles the performance of insulated ST systems.

With these figures, payback period of ST systems can be substantially reduced.

Additionally, in common DH systems, there is only a small share of buildings with ST systems connected to the DH network. In this context with marginal contributions of ST systems to the DH network, there is no need to configure ST systems to raise fluid temperature to the overall flow temperature in the DH network. ST systems may be confirgured to deliver the maximum possible heat to the return pipe of the DH system.

Considering performance levels declared in a Solar Keymark certified flat plate ST collector, performance of the collector itself is improved by an average 0.58% for every ºC of reduction in the operation temperature of the ST field. This reduction is greater for ST systems operating at 70-90ºC (0.7%). Considering DH operational conditions with ATs in the range of 30ºC, the performance level of ST ststems can be improved by ~20%.

Also, by selecting the connection scheme withoun local storage (c), local heat losses in the storage tank are avoided.

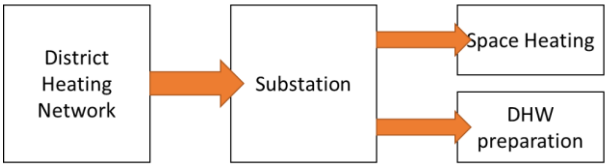
All this can be converted in a 80-140% of increase in the heat output of the ST systems along the year. Even when considering that the cost of heat during summer times might be reduced by 30%, there is a substantial increase in the economic output, in the range of 60-100%.

Additional improvements can be achieved due to the professional operation of the DH connected ST system. Under this scheme, maintenance costs can be substantially reduced while at the same time better service level can be achieved.

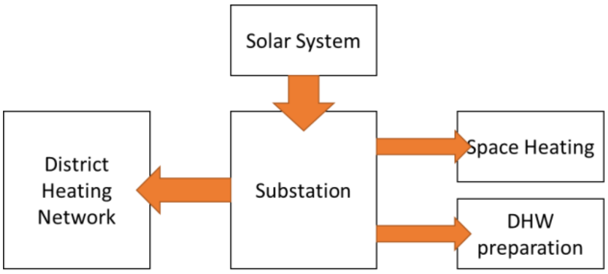
Furthermore, with DH connected ST systems as those defined in this work, DH operators could potentially deliver Energy Services uner ESCO approaches. "Rent-Your-Roof" approaches, which are developped as investment-free alternative for the installation of PV in buildings, can then be applied to the installation of ST systems.

6. PROPOSED OPERATIONAL SCHEME

ST heat production and heat load curves are not coincident. During winter time, it can be expected that all ST will be used within the building. During summer time, heat production can be expected to be larger than heat needs within the building. For this reason, in order to utilize correctly the heat captured by the ST installation, this heat should be made available both at local level, and delivered to the DH network.



Heat delivery scheme in state of the art DH substations



Proposed heat delivery scheme for ST energy

Considering this operational scheme, the integration of ST systems in DH, as proposed in this work, requires a heat purchase policy to be implemented by Dh operators. Bi-directional and/or net-heat metering devices should be installed in the substation.

7. LIMITATIONS OF CURRENT SUBSTATIONS

Currend DH substations are conceived for heat delivery from the DH into the building. Both for space heating and DHW. There are different configurations, depending on the use of direct/indirect methods for space-heating and DHW, but in terms of flexibility, all substations are operated in the same manner. Under these configurations, no bi-directional heat transfer is possible.

In order to propose suitable substations for the new operational scheme, the following items need to be considered:

- 3-service substations are required: Solar, Space heat, DHW
- Bi-directional and/or net heat meters are needed
- Reverse pumping needs to be incorporated in order to pump water from the return pipe back into the flow pipe
- Control needs to be coordinated with ST loop

8. ALTERNATIVE SUBSTATION DESIGNS FOR DH-CONNECTION OF ST

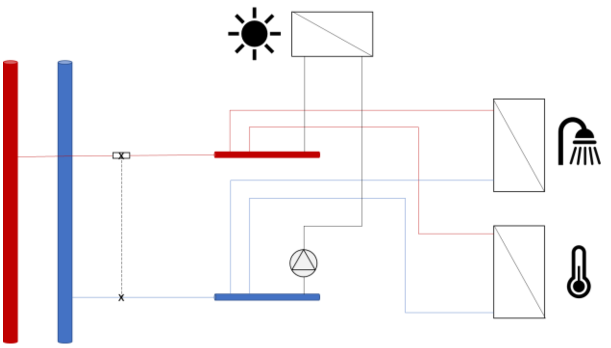
The proposed substation configurations are based on a 3-heat exchanger concept. Each of theser heat exchangers independizes on of the circuits within the building: Space Heating, DHW and ST system.

Depending on the configuration of each particular ST system, the solar part of the circuit can be configurated as required. Variations such as presurized/drainback systems, with water and/or thermal fluids, and pontential local storage are possible.

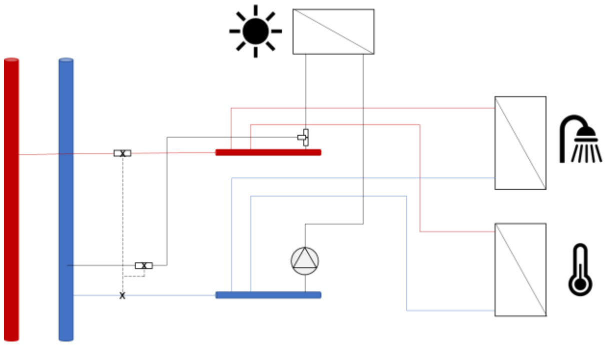
For Space heating and DHW, regular DH substation configurations are proposed. Again, depending on network and building particularities, DHW storage can be added.

2 configurations are presented which differ in the connection of the ST loop with the DH grid:

- 2-pipe configuration: ST is connected at high temperature
- 3-pipe configuration: ST heat can be delivered either at high or low temperature levels.



Proposed substation concept with a 2-pipe arrangement



Proposed substation concept with a 3-pipe arrangement

The 2-pipe substation can in principle be used to connect ST systems into buildings with already-existing DH connections (2 pipe). Of course, an agreement would be required for energy billing with a net-metering approach.
3-pipe substations imply changes in the connection of the building to the distribution network. As such, it is only recommended for large buildings, or for situations where changes are expected in the network anyhow. In this case, a net-matering approach is followed for heat consummed/injected at high temperature, while a secondary meter is used to account for heat injected at lower temperature, potentially at a lower price.

9. CONCLUSIONS

The incorporation of distributed ST in DH networks presents a clear opportunity to de-carbonize heat production in such environments. At the same time, this kind of installations presents substantial benefits over issolated ST systems:

- Heat production is much larger
- Cheaper system, as thermal storage is no longer needed
- Provide better economic metrics due to the possiblity to sell excess heat
- ST systems are better commissioned

At the same time, these installations need to be promoted by DH operators, with the implementation of heat purchase strategies.

Substations need to be adapted to the new configuration, with additional heat exchangers for the ST system, net meters, and reverse pumping capacity.

10. FUTURE WORK

Substations for the connection of ST into DH networks will be developed within (RELaTED, 2017). Within this project, several substation concepts will be engineered, prototyped, tested and deployed over 4 pilot DH setups across Europe. Deployment of such devices is expected in 2019.

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