Task 55 Towards the Integration of Large SHC Systems into DHC Networks

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Integration concepts of central ST systems in DHC

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Subject:	Integration concepts of central ST systems in DHC
Description:	Hydraulics and control of central ST integration in DHC systems Heat pump integration to increase the ST share
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This factsheet focuses on the integration hydraulics and control of central ST systems in DHC. The first part gives an overview of the typical integration concepts and operating modes implemented in the state of the art. The second part illustrates general aspects of the integration of heat pumps to achieve higher shares of ST and describes recent projects: two implementation projects (Crailsheim and Salzburg-Lehen), and one feasibility study performed by the Technische Universität Dresden.

Hydraulics of central solar thermal integration in DHC systems

In DHC networks with central solar thermal (ST) production, the solar systems are typically installed in combination with other heat-only or CHP plants or with plants and with a thermal storage unit [1]. The forward temperature of the solar collector field is typically controlled by variable flow, depending on the heat demand and the solar radiation. When solar heating is implemented to existing district heating plants, the solar feed-in connection is adapted to the existing conditions. Generally, the feed-in method is return-to-supply. Several feed-in modes are possible though, mainly depending on the temperature of the solar system and of the district heating network, on the boiler type and on the characteristics of the heat storage. For example, some boiler types need a low (constant) inlet temperature, while other boiler types can work efficiently even at rather high inlet temperatures. In presence of hot water storages with several diffusors (inlets/outlets), the ST system can be operated to heat water at a middle temperature, so that higher ST efficiencies are possible.

Changing between the different ST operating modes are done automatically by a supervisory control system acting on valves and pumps of the ST plant and selecting the operating mode depending on the values of the measured variables, as described in the following schemes.

Following colour codes are used to represent the different temperature levels:

- RED: Warmer than district heating forward temperature
- PURPLE: District heating forward temperature
- ORANGE: Close to district heating forward temperature
- YELLOW: Warmer than solar collector inlet temperature
- LIGHT BLUE: Solar collector inlet temperature
- DARK BLUE: District heating return temperature

The possible operating conditions, depending on the set-point of the ST outlet and of the network supply temperature, on the irradiance, and on the system constraints, are:

a. **ST outlet temperature = DH supply temperature.** When the ST system is operated with the purpose to deliver heat at the same temperature as the DH network supply line, the solar heat can be utilized directly (or stored, if in excess): this is the so-called integration scheme return-to-supply (Figure 1).

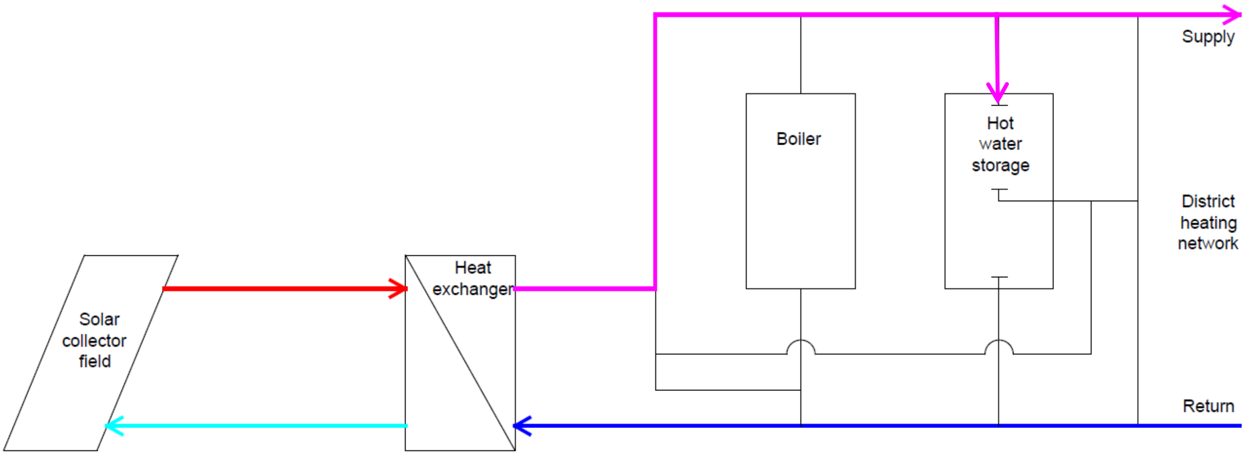

Figure 1. Return-to-supply integration of ST

b. **ST outlet temperature < DH supply temperature.** The advantage of operating the ST system at lower outlet temperature than the DH network is the higher ST efficiency. This might be beneficial especially in the winter, when auxiliary heat sources are needed even when the sun is shining.

When the solar collector forward temperature is lower than the district heating forward temperature, the district heating flow temperature needs to be raised by alternative heat sources. This temperature lift can be performed using other heat production units (boiler in this case) or utilizing heat from the hot water storage:

1. **Indirect Return to Supply.** For boilers requiring a low inlet temperature (e.g. condensing biomass boilers), the forward temperature of **the** solar collector field can be mixed with the forward temperature of a boiler. This mode is defined as *indirect* return-to-supply (Figure 2).

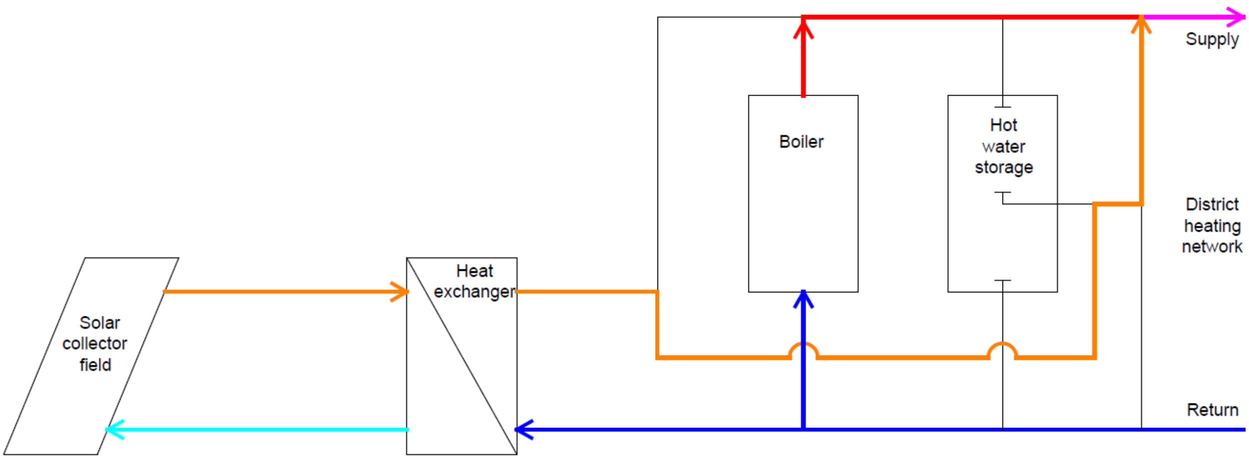

Figure 2. Indirect return-to-supply integration of ST

2. **Preheat of the boiler.** When the boiler is insensitive to the inlet temperature, the solar heat can be used for preheating in the winter period. This mode is close to return-to-return (Figure 3).

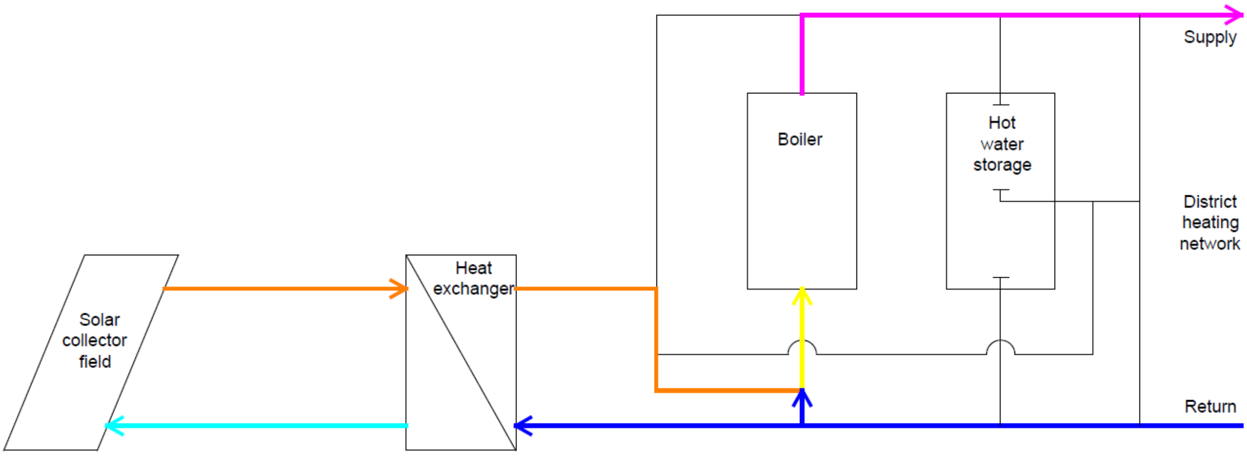

Figure 3. Integration of ST as boiler preheater

3. **In combination with hot-water storage.** In periods with lower solar collector outlet temperature and high storage temperature (e.g. during startup) the solar forward temperature can be used for shunting with the outlet of the top of the storage (Figure 4).

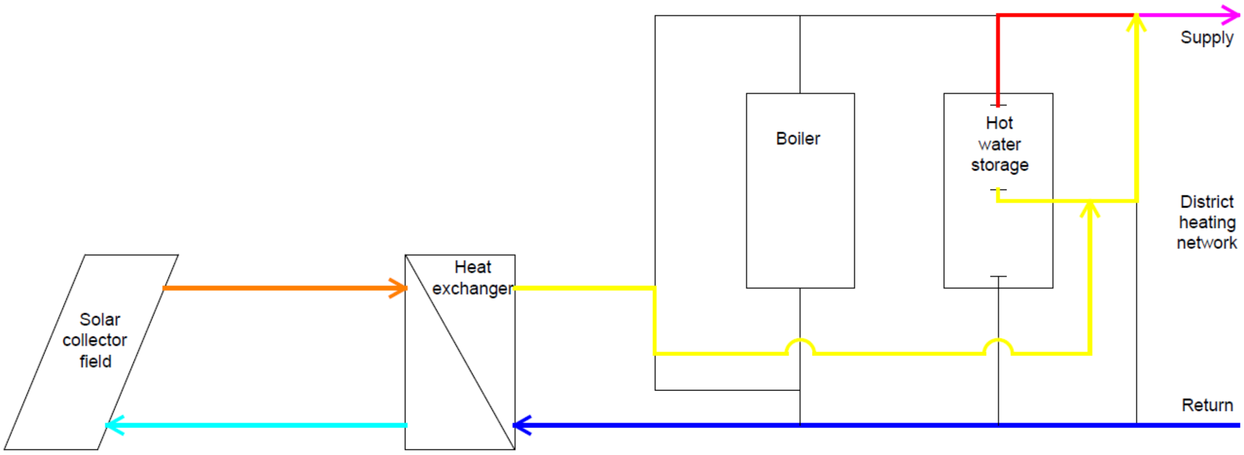

Figure 4. Integration of ST in combination with hot-water storage

c. **ST outlet temperature > DH supply temperature.** If the ST system is operated at a temperature higher than the DH supply, cold water from the middle range of the storage or from the district heating return can be used to cool down the forward temperature. In this way the valuable hot solar heat can be saved and stored for a later use.

1. **Storage as shunt.** The storage is charged from the top while discharging from the middle. Cold water will flow into or out of the bottom of the storage, depending on if the district heating flow rate is higher or smaller of the solar heating flow rate (Figure 5).

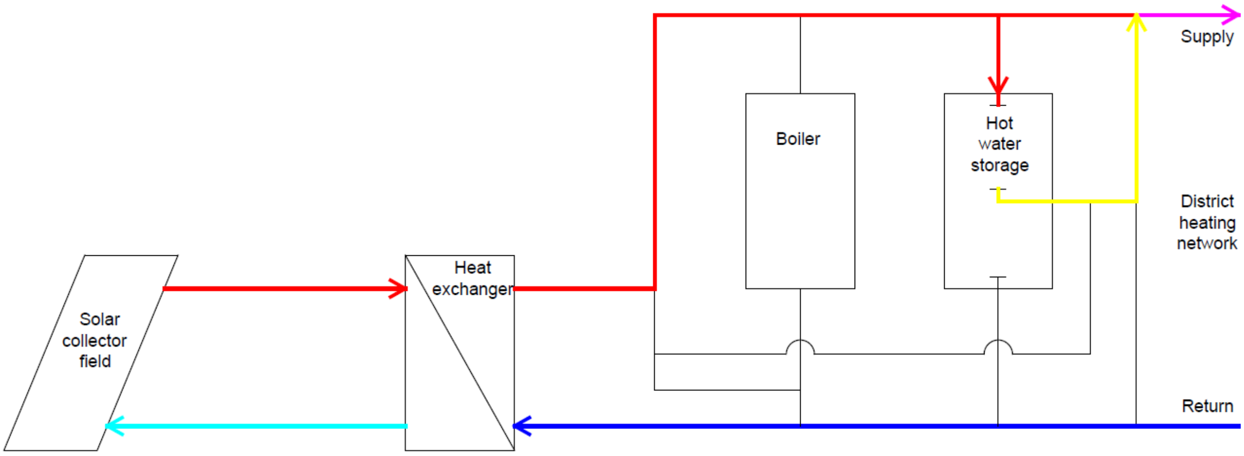

Figure 5. Integration of ST with storage as shunt

2. **Cold return shunt.** If the storage temperature of the mid-layer of the storage is too high to use for shunting, the district heating return flow can be used (Figure 6).

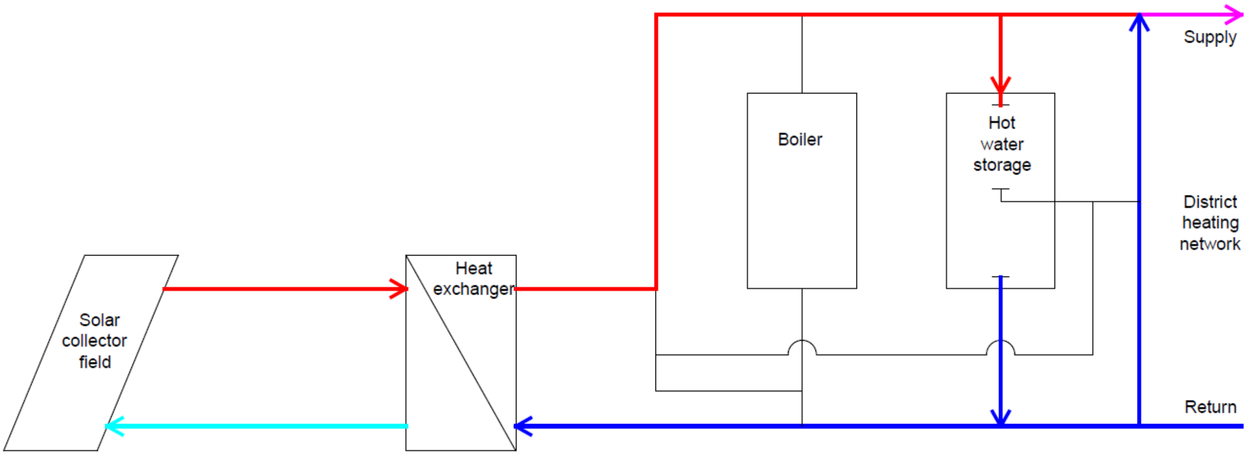

Figure 6. Integration of ST with return as shunt

Heat pump integration

General aspects

Heat pumps can be integrated into SDH/SDC systems to achieve higher shares of ST (and renewables in general) and thus reduce or replace the use of fossil fuels. Basically, heat pumps enable:

- Lower storage temperatures, reflecting in lower storage thermal losses and higher ST efficiency;
- Higher store capacities, thanks to the higher difference between maximum and minimum temperature;
- Power-to-heat options, which unlock flexibility for the integration of volatile energy sources.

In general, it is preferred not to have a heat pump discharging directly into a large-scale TES, as it would cause back-mixing and disturb the stratification. As a sink for the heat pump, it is usually better to consider an additional (smaller) buffer, as represented in Figure 7. However, it is to consider that the additional buffer would require higher investment costs and increase the thermal losses.

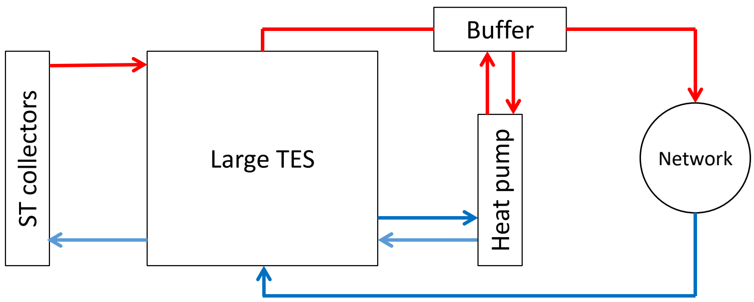

Figure 7. General integration scheme of ST with large TES and heat pump

Integrating a heat pump in a SDH/SDC is expected to bring environmental benefits. However, of course, the scenario assessment and the optimization must consider the electricity source of the heat pump and possible mismatches between electricity demand and availability of renewable sources. As these quantities are typically time-dependent, an idea proposed in [2] is to define time-dependent primary-energy conversion factors, taking into account the time of electricity use. With constant (yearly average) primary-energy factors, the benefit of using a heat pump can be overestimated (the heat pump is more used in winter to discharge the TES, i.e. with energy supply mix more fossil than in summer).

Crailsheim (Germany)

The DH system Hirtenwiesen II in Crailsheim represents the largest solar DH plant with seasonal TES in Germany. In 2014, the solar collectors generated about 1,960 MWh (about 40% of the 4,900-MWh total network demand). The collectors are mounted on two noise barrier earth berms (example in Figure 8) as well as on several buildings, with a total aperture area of about 7,500 m^2.

Figure 8. ST collector fields on a noise barrier earth berm in Crailsheim (Source: SOLITES)

A description of the system is available in [3], to which the quoted text refers. The ST and heat pump integration concept is illustrated in Figure 9. The solar collector arrays and the heat pump supply the DH grid Hirtenwiesen II. The system includes also two hot water tanks (480 m^3 and 100 m^3 respectively) and one borehole TES (39,000 m^3, water equivalent 10,000 m^3). As in winter "*the solar thermal collectors and the heat pump do not cover the entire heat demand of Hirtenwiesen II, additional heating is provided by the DH grid Hirtenwiesen I, which is supplied by a thermal plant.*" The DH grid Hirtenwiesen I can also be reversely used as heat sink "*when there is a too high solar thermal output. In this way, collector stagnation is prevented.*"

The heat pump has an electrical power of 80 kW and "*is hydraulically integrated between the two hot water buffer stores. This enables long operation cycles, since the heat pump works with large volumes on both evaporator and condenser side. Furthermore, drawing heat from the buffer store 2, the heat pump lowers the temperature of this storage, which increases the efficiency of the solar collectors [...] In 2014, the heat pump electricity consumption was about 250 MWh.*"

Simplifying, the upper part of Figure 9 (i.e. the ST collectors on the buildings and the storage tank 1) is designed to cover the base load of the network, while the lower part (i.e. the collector fields on the two earth berms, the buffer storage 2 and the borehole TES) is mainly thought for seasonal operation, i.e. to store in the borehole TES the summer ST excess and deliver it in winter. The buffer storage 2 is necessary "*because the thermal power output of the collectors is higher than the charging capacity of the borehole. Hence, the collectors do not charge the borehole TES directly, but through the buffer storage 2.*" Furthermore, if necessary, the buffer storage 2 can be used to prevent stagnation also for the collectors installed on the buildings when the buffer storage 1 has not sufficient free capacity [3].

In 2014, about 720 MWh of heat were transferred into the borehole TES, while about 310 MWh were taken out, which corresponds to an efficiency of 43%. This low efficiency is due to the limited charging and discharging power of the borehole.

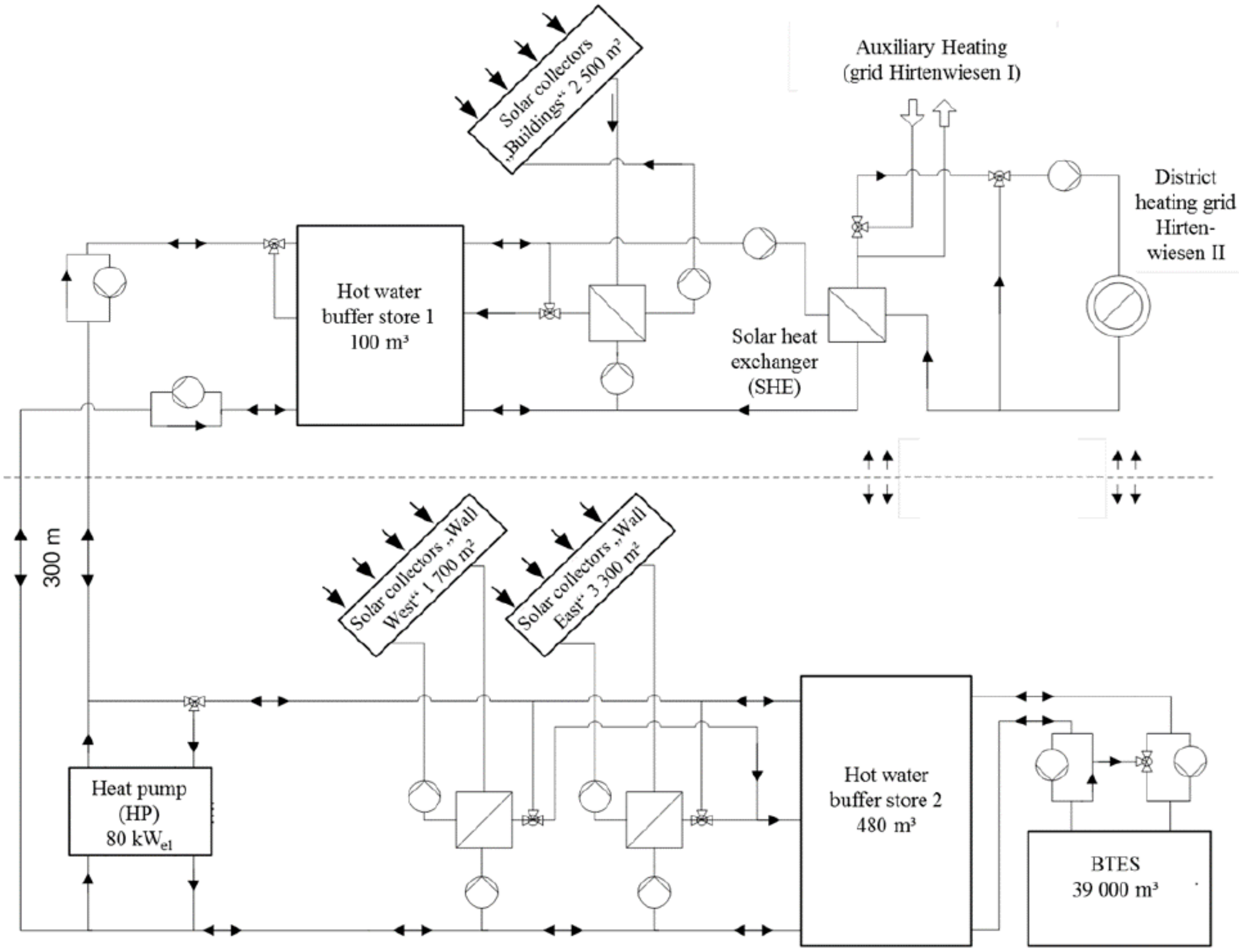

Figure 9. Hydraulic scheme of the SDH system in Crailsheim (Source: [3])

Salzburg-Lehen (Austria)

In the district of Salzburg-Lehen (Figure 10), a new residential area with about 3975 MWh/a heat demand (including about 400 MWh/a heat losses) is provided with a local low-temperature micro-network receiving heat from the main DH network of Salzburg and from a local ST system with a 160-kW_{th} heat pump and a 200-m^3 hot-water storage. The hydraulic scheme is reported in Figure 11. The solar collectors are mounted on rooftops and have an overall area of 2047 m^2 (aperture area 1855 m^2) split into 13 separate collector fields. The operation of the ST plants started up between 2011 and 2013. In the period August 2013 through July 2014, the measured ST production was 989 MWh. The annual solar yield and the ST share of the microgrid resulted then 533 kWh/m^2_{ap} and 25% respectively.

Figure 10. Views of the district Salzburg-Lehen

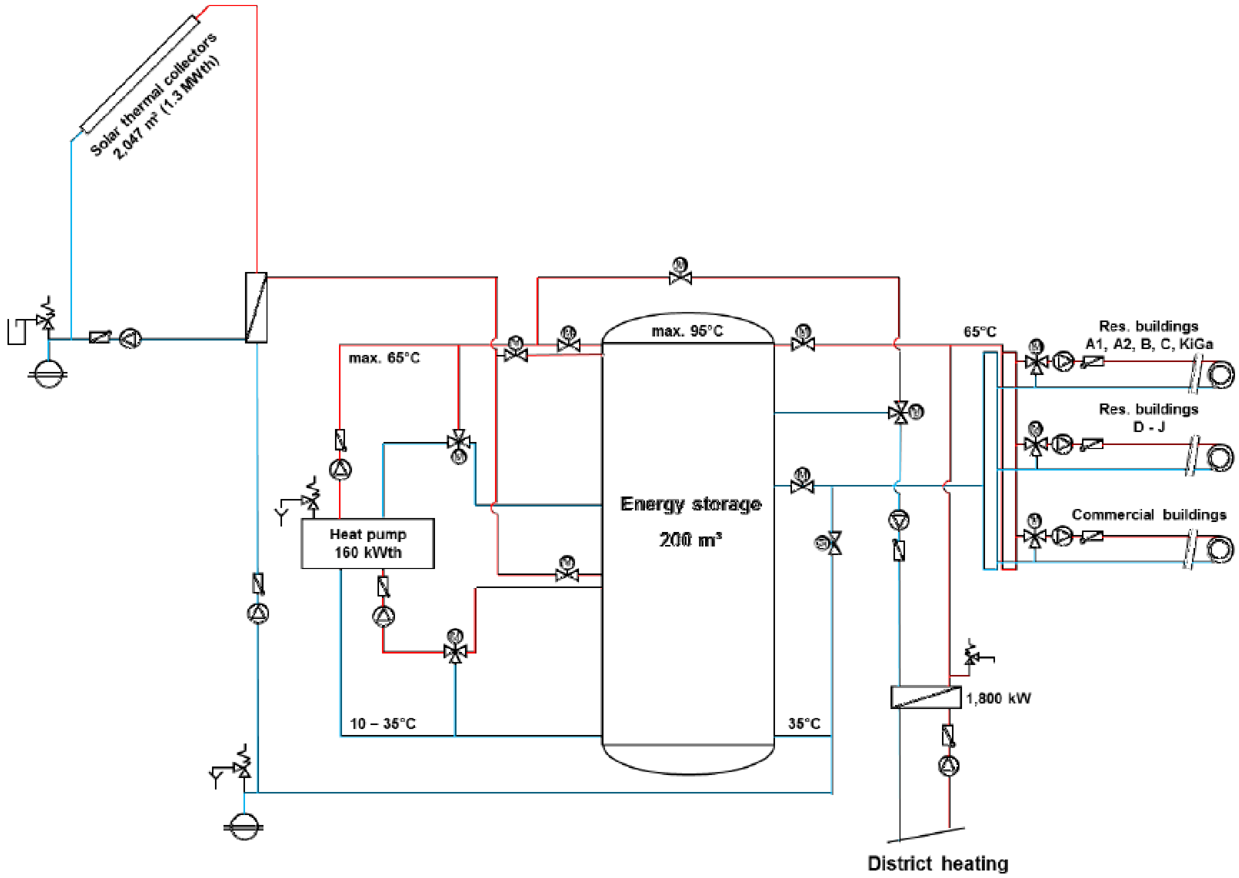

Figure 11. Hydraulic scheme of the heat supply system in Salzburg-Lehen (Source: AEE INTEC)

Feasibility study in Germany

Another option for central integration of ST and heat pump in a DH system is represented in Figure 12, referred to a German feasibility study. The elements within the dashed contour line (large-scale TES, ST, heat pump) are supposed to be integrated in an existing DH system based on gas-fired CHP plants (48 MW_{el}, 51 MW_{th}). The heat pump uses the DH return line as a source and the ST output as a sink, allowing than both plants to operate at return temperatures lower than the DH return, what results in an increased efficiency of both CHP and ST. Furthermore, the CHP plant operation can be better adopted to the spot market prices for electricity. The size of the new plants are identified based on an optimization algorithm. The study underlines that the operation of heat pump and ST is economic feasible only when the spot market prices for electricity are very low, the ones for gas are very high, or the costs for CO_2-certificates are very high [4].

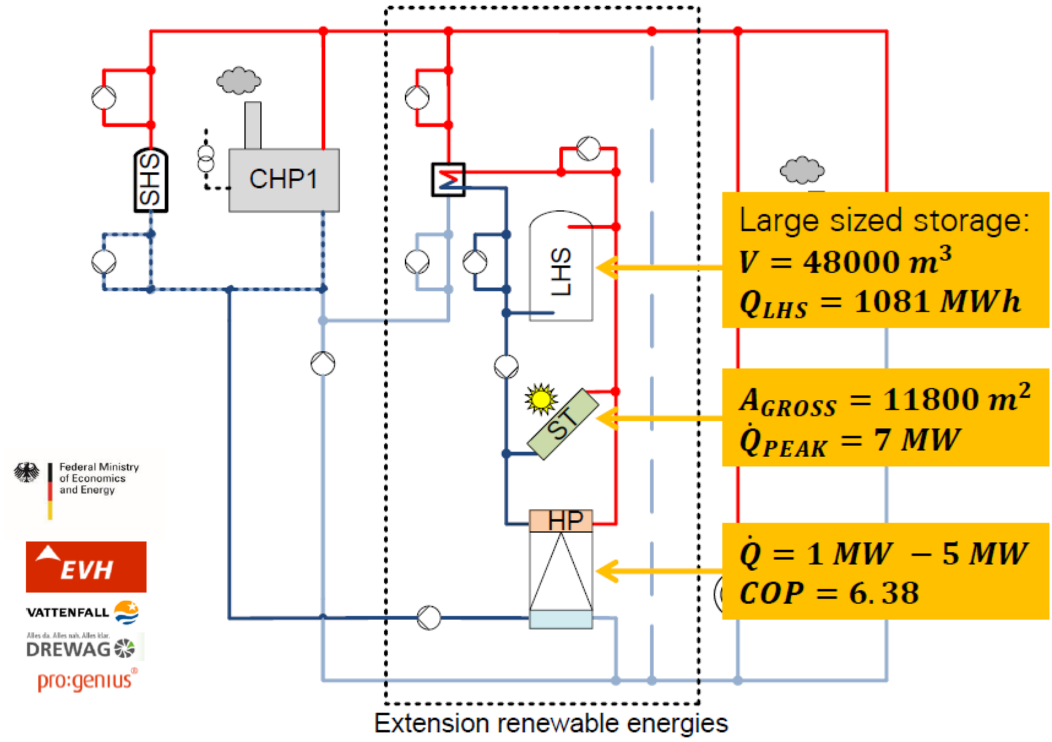

Figure 12. Concept for integration of ST and heat pump in an existing DH system (Source: [4])

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