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

Integration concepts of decentral ST systems in DHC

IEA SHC FACT SHEET 55.A.3.2

Subject:	Integration concepts of decentral solar thermal systems in DHC
Description:	Hydraulics and control of decentral ST integration in DHC systems Hydraulics of ST integration on the secondary side (without feed-in) Best-practice examples
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Contents

This factsheet focuses on the integration hydraulics and control of central ST systems in DHC. The first part gives an overview of decentral feed-in: international state of the art (including comparison and selection criteria of the different integration schemes), hydraulics and components, details of the return-to-supply scheme (challenges, pump operation, control). The second part describes concepts for the secondary-side integration of ST without feed-in. The third part illustrates selected best-practice examples in Austria (Wasserwerke Andritz and Berlinerring in Graz) and Sweden (Ystad).

Overview

Figure 1 gives an overview of the theoretically possible ways to combine solar thermal (ST) with district heating and cooling (DHC) systems [1]:

- Central connection of ST to the DHC network (subject of the factsheet [2]);
- Decentral connection in four different schemes with ST feed-in as priority (lower side);
- Decentral connection with building supply as priority (upper side);

All these three combinations are possible in the same DHC system and they normally do not affect each other.

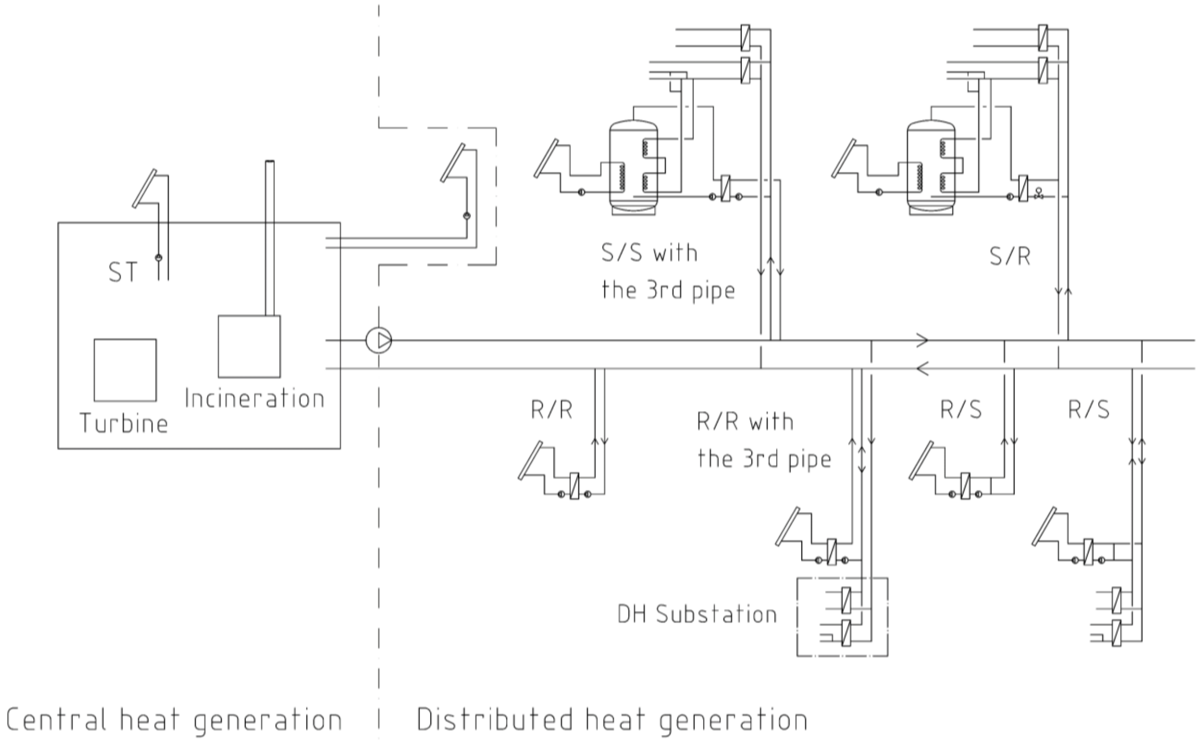

Figure 1. Integration schemes of ST in a DHC system (Source: [1])

In general, important differences exist in the roles, the boundary conditions, and the operation of central or decentral ST systems. In particular:

- Central ST have a heat production responsibility (together with other central heat sources), while decentral plants have usually not;
- Decentral ST plants with return-to-supply feed-in scheme are required to produce heat at an assigned temperature, while central ST plants are not;
- Consequently, a return-to-supply ST feed-in needs a more advanced control than a central ST plant.

Concepts for decentral feed-in of heat from ST in DHC systems

State of the art

The theoretically possible feed-in schemes of decentral ST installations are four [1]:

- Return-to-return (R/R)
- Return-to-supply (R/S)
- Supply-to-supply (S/S)
- Supply-to-return (S/R)

All these options can use either proper connections to the DHC network or the same service line used for the customer substation. If connected through the line of the substation, for the R/R and S/S schemes a third pipe is necessary.

In general, the S/S and S/R schemes are used for ST installations with building supply as priority, while feed-in acts as a sort of overheat protection or stagnation prevention system. The most relevant integration schemes for decentral ST with feed-in as priority are in the practice R/R and R/S.

The report [3] illustrates 31 case studies in Austria, Denmark, Germany, and Sweden, and analyzes potential and barriers for optimizing the integration. In 29 cases the connection is return-to-supply, in one case is return-to-return, and in one case both options are possible. The feed-in pump is always provided with inverter to regulate the water flow. In some cases, a control valve is also installed to allow a more accurate control. The control system acts on the pump speed and on the valve opening, manipulating than the pressure head and feed-in flow and guaranteeing the desired feed-in temperature (flow-controlled feed-in, more in detail explained in the dedicated section at page 13, see Figure 8). In some existing installations, additional solutions are implemented to smooth the effects of possible rapid pressure changes in the network:

- A by-pass with flow limiter or lamination valve from the supply to the return line of the solar station, to accelerate the control dynamics of the solar station loop;
- A hydraulic separator, particularly in cases of high network pressure, which allows operating the entire solar station loop at lower pressure than the feed-in line. This solution is also supposed to enable a stricter temperature control when the ST power rapidly changes: in fact, the rapid flow changes necessary to maintain the desired temperature would not cause water hammers in the network if the feed-in and the solar station loops are separated. Of course, the two loops (feed-in and solar station) need a dedicated pump each. However, the hydraulic separator makes the feed-in system more complicated and increases the thermal losses, so that in general it should be avoided.

Table 1 summarizes the main differences between return-to-return and return-to-supply feed-in, while Table 2 classifies the existing integration concepts according to different criteria (feed-in scheme, solar heat priority, hydraulics, feed-in temperature) and summarizes the main characteristics.

Table 1. Main characteristics of return-to-return and return-to-supply decentral feed-in (elaborated from [4])

Return-to-return	**Return-to-supply**
Need for a third pipe when installed together with a substation	No need for a third pipe
No particular requirements on the feed-in temperature	Strict requirements on the feed-in temperature
Increase of the network return temperature	No or small effect on the network temperature
Feed-in pump with low pressure head	Feed-in pump with higher pressure head
Very simple control system	More advanced control system
No effect on the network flow	Effects on the network flow
Feed-in flow depending on the network flow rate	Feed-in flow independent of the network flow rate
Possibility of feed-in capacity temporarily above 100% network demand, if installed on a branch with enough flow rate	Feed-in capacity limited to lower shares of network load, as the feed-in pump cannot given supply responsibility
No need for storage if ST production exceeds the network demand for short time slots, if installed on a branch with enough flow rate	Possible need for storage even if ST production never exceeds the network demand, as the feed-in capacity is limited

Table 2. Classification criteria of the existing decentral integration concepts (elaborated from [3] and including authors' integrations)

Classification criterium	Option	Possible reason for the selected option
Feed-in scheme	Return-to-supply	Changes of network return temperature are to avoid (e.g. not to increase the network losses or decrease the efficiency of other generators) Feed-in tariff higher than in R/R scheme Need for solar heat at usage temperature
	Return-to-return	Network supply temperature is too high to reach for the decentral plant Feed-in in the vicinity of central plants High pressure difference between supply and return Pressure difference highly fluctuating
	Combined	Decision to combine the advantages of the previous options (however, it is more expensive, therefore mainly realized for pilot tests)
ST usage priority	Network	Low investment cost (storage avoidable) Long invoicing periods High feed-in tariff
	Building	Low feed-in tariff Short invoicing periods High heat cost from DH network Restrictions from building regulation
Hydraulics	Single feed-in pump	No significant fluctuation of pressure difference between network supply and return No need for accurate control Almost steady feed-in power
	Two feed-in pumps	Combination of pumps to enlarge the operating field
	Feed-in pump + control valve (s. Fig. 8)	Rapid fluctuations of pressure difference between network supply and return Large flow variability is desired Need for accurate control
	Bypass (s. Fig. 9)	Rapid fluctuations of pressure difference between network supply and return

		Need for temperature-controlled feed-in (e.g. decentral plant has constant and limited temperature raise) Need for very small feed-in flow (e.g. to avoid freezing or cooling of the connection line)
	Hydraulic separator	High pressure difference between network supply and return
Feed-in temperature	Same as network supply	Need for uniform supply temperature over the network, in particular not to affect the supply temperature of the downstream substations and easily guarantee them the security of supply
	Constant	Desire to increase the solar production No need for uniform network supply temperature
	Changing e.g. with the season	Combination of the advantages of the above options
	Fixed raise of the return temperature	Return-to-return feed-in

Figure 2 shows in more detail three possible ways to realize a decentral return-to-supply feed-in:

- Feed-in in series with ST supply of a building (as stagnation prevention, like in scheme B);
- Feed-in in parallel with ST supply of a building (like in scheme C);
- Feed-in without connection to any building side (like in scheme D).

Finally, a decentral ST installation can also be connected only to the building side, as shown in Figure 2 scheme A. In this case, the ST plant supplies just the building and no feed-in is realized.

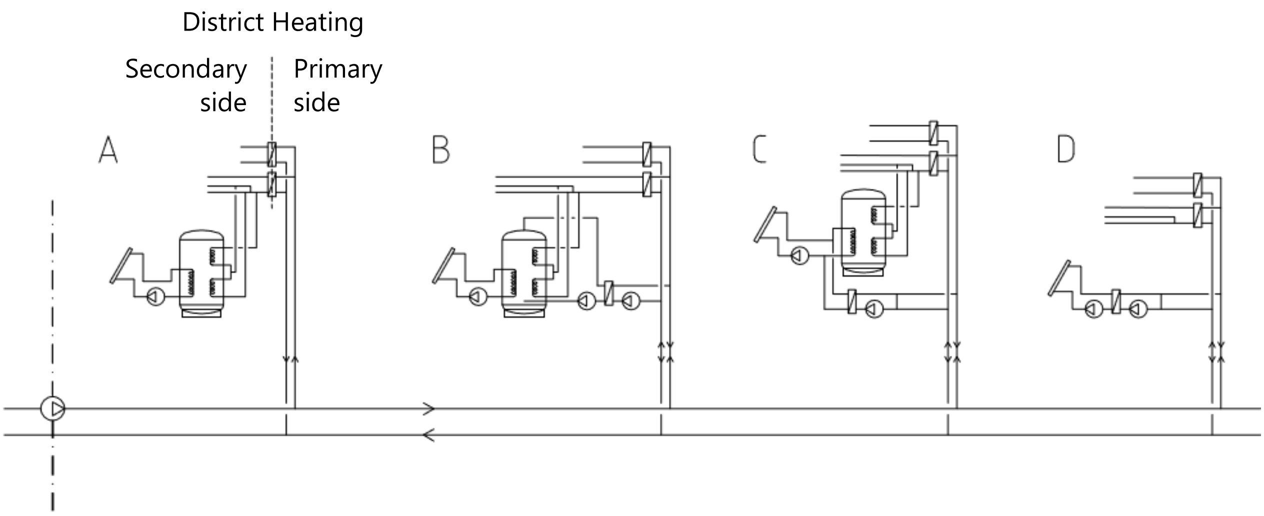

Figure 2. Integration schemes of decentral ST plants in a DHC system (Source: [1])

Feed-in hydraulics

Contrarily to large central solar installations, the storage unit is not necessarily present in the decentral plants. However, the line between solar station and network must be properly sized to ensure the necessary heat flow; as a general rule, it is to consider a maximum velocity of 1-1.3 m/s to feed at least 800 W/m^2 ST production [1] (with such a design, ST peaks above this production value will result in temporarily and not dramatic temperature rises). The study [3] highlights that the use of already existing user connections (e.g. Figure 3 left) can be an important hydraulic bottleneck limiting the solar share much more than the available roof area. Solutions to this issue can be:

- Adding new appropriate connections (e.g. Figure 3 right) and/or storage units
- Use the speed as a flow limiter instead of the pressure drop (a flow up to 1.3 m/s for short times is usually feasible)
- Increasing (locally and temporarily) the temperature difference between supply and return line, in order to allow the same heat flow from the solar station at lower flow rates. Of course, the feasibility of this solution depends on the operational flexibility of the system, in particular of the collector loop.

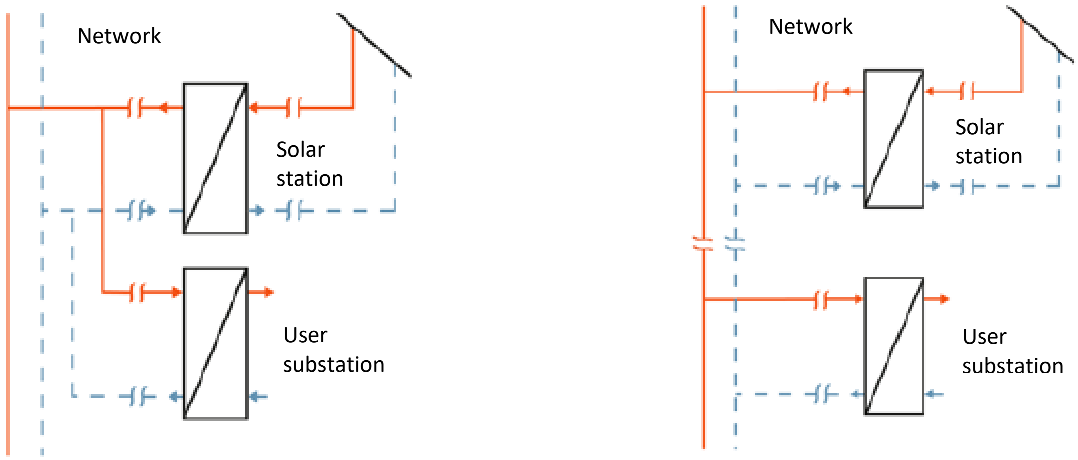

Figure 3. Decentral integration of ST using existing (left) or dedicated connections (right) (Source: [3])

As expected, the best solutions are highly case-sensitive. In general, the storage is recommended when the operational priority is to maximize the solar usage of the prosumer, supplying then the network just with the heat excess (see schemes B and C in Figure 2); in such cases, the decentral feed-in can be in series (downstream) or in parallel with the local ST usage. Compared with a ST installation without feed-in (see scheme A in Figure 2), feed-in as overheat protection system allows installing larger collector areas, increasing then the ST building supply with the same storage volume, and/or installing smaller storage volumes without decreasing the ST building supply.

If, on the contrary, the priority is to maximize the feed-in, solutions without storage can be preferred, as the storage would require additional costs and increase the heat losses. However, in R/S schemes the thermal storage can be avoided just up to a certain collector area: in fact, if the feed-in heat power is large in comparison with the DH-system, stagnation risk is to consider and prevent. An exact limit is difficult to specify because highly depending on the design of the DH network and of the central heat production plants. As calculated in [5], a reasonable limit for installations without storage (and with very short stagnation periods) is a ST capacity of about 10% of the maximum heat load of the entire network. According to simulations, the corresponding ST share results about 25% in summer (3-4% over the year) in case the pipe system is used as a short-term storage. However, using the pipe for thermal storage is acceptable just as exception, since higher pipe temperatures increases the thermal losses and reduce the T efficiency.

For the local thermal storage there are four possible locations:

1. In the collector loop: this solution can be expensive if a heat carrier different than pure water is used; furthermore, the collector loop is the hottest loop of the system, so that the heat losses would be the highest.
2. On the network side (see Figure 4 left): this solution can be expensive if the network pressure class is high (e.g. PN16).
3. On the building side (see Figure 4 right), with the advantage of lower pressure than in the point above.
4. As a closed system between collector and building loop, with heat exchangers on both sides. The storage design for this solution is cheap, as a low operating pressure and pure water as storage medium can be used. However, indirect heat-exchange connections on both sides would force the collectors to operate at higher temperatures to supply the building, resulting than in lower efficiency. This solution is represented above in Figure 2, schemes A, B, C.

Between the 31 cases analyzed in the above-mentioned study [3], just two of them have decentral feed-in in combination with a thermal storage, each with a different integration scheme. Figure 4 left illustrates the solution adopted in Skive (Denmark), where the prosumer is directly connected to the network. The concept, which corresponds to the above-listed point 2, is simple but not always easy to implement, because the storage must operate at the network pressure, which in some systems can be rather high. Figure 4 right on the right illustrates the solution adopted in Graz (Austria) for the decentral feed-in from Wasserwerk Andritz.

Here, the prosumer has an indirect connection to the heat network. This solution requires more components, but, on the other hand, the storage operates at the pressure of the building-side system as in the above-listed point 3.

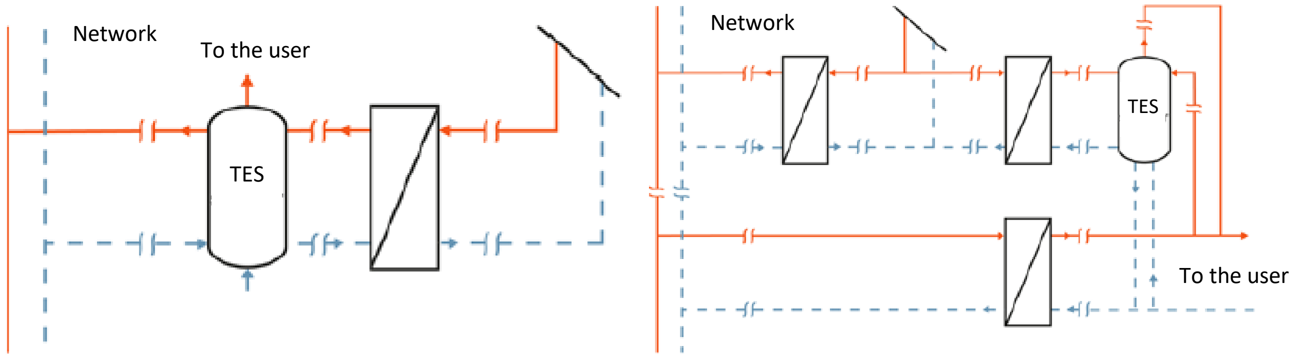

Figure 4. Decentral integration of ST with storage: Skive (left) and Graz (right) (Source: [1])

Challenges of R/S scheme

Integrating decentral heat or cold producers in a DHC system in a R/S scheme can temporarily modify the flowdynamics in some network sections [6, 7]. The entity of the effects depends on the ratio between the feed-in and the network heat flow. Possible temporary effects, especially if the supply point is in a peripheral zone (s. Figure 5), are:

- Inversion of the stream direction (i.e. a negative mass flow)
- Lowering of the differential pressure at the feed-in point: for this reason, it is important that feed-in does not directly affect the differential pressure sensor used for the network pump control

Although literature [8] considers the case of temporary points with stagnating water (so-called supply frontiers) causing temperature fluctuations, as well as the possibility for these supply frontiers to move along the network according to the load conditions and potentially give rise thermal stresses, such effects are quite seldom and limited to systems with customers very far from each other.

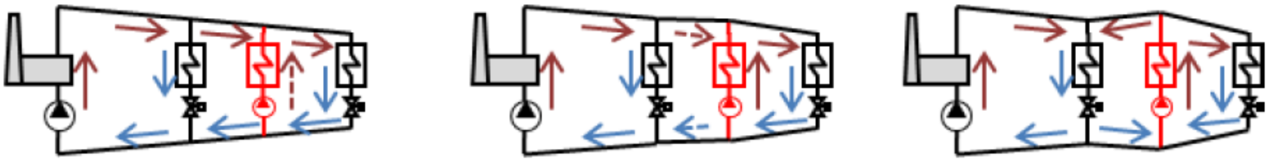

Figure 5. Effects of decentral feed-in (Source: [7])

Additional operating challenges of decentral R/S-feed-in are due to possible fast and significant changes of:

- Return temperature: while the return temperature to the central plants is typically fairly stable, the return temperature to decentral plants can vary quickly, in particular if they use the same connections of customer substations (as in Figure 4 left) and if the feed-in flow is comparable to the return flow from the local substation.
- Differential pressure at the feed-in point: the changes represent a challenge for the R/S feed-in pumps, which must give a higher pressure-head than the differential pressure at the feed-in point; this differential pressure can change significantly and very fast [1].
- ST heat power: the feed-in system must feed in the same power as produced, which can vary quickly and significantly; if the ST production becomes very low, it may become necessary to switch to a R/R scheme or to set the production to zero if the system does not allow to switch.

Pump operating range in the R/S scheme

The red circles in Figure 6 indicate the components of the feed-in pressure head in a R/S scheme:

1. Flow-dependent pressure drop in the feed-in station, mainly due to the heat exchanger, the flow sensor, and the control valve V2. The maximum value of this pressure drop in a good system is typically in the range 40-60 kPa.
2. Flow-dependent pressure drop in the service line. Here, the flow has typically a maximum speed of about 1 m/s and the corresponding pressure drop is very system-depending. 50 kPa can be roughly considered as order of magnitude.
3. Flow-dependent pressure drop in the network line, e.g. as represented by the piezometric lines in Figure 5. Apart from the special case of the feed-in station at the end of the network, the value of this pressure drop is not simple to assume or calculate, and a code is necessary.
4. Differential pressure, which is with good approximation independent of the feed-in flow. This component is often the highest one of the four when the control valve V2 is 100% open, especially for small- and medium-sized ST installations.

The feed-in pump, indicated with P2 in Figure 6, is requested to overcome these flow resistance components. Figure 7 reports typical characteristic curves of a pump at different speeds (in steps of 5%) and two different feed-in flow control modes:

- Constant opening of the control valve (here 100%) and flow controlled just by regulating the pump speed: in this case, a feed-in curve corresponding to the characteristic curve of the line (following the red stars) will be obtained. The flow is zero when the pump head is below the differential pressure, here obtained at a pump speed of 40%, above which it increases very quickly at small increments of pump head. Such a behaviour makes very difficult an accurate control of the feed-in flow.

- Constant pump speed (here 80%) and flow controlled just by regulating the opening of the control valve: in this case, a feed-in curve corresponding to the characteristic curve of the pump at that speed (following the black stars) will be obtained. Such a curve allows a much more accurate flow control.

Furthermore, it is important keeping the feed-in operation within the blue area, which represents the appropriate operating field for the pump. Pump manufacturers have different opinions about what happens when the pump operates in the white area underneath this field; however, those who have been asked strongly advised to avoid it. Operation in this area can happen above a certain pump speed (here >70%) if the flow-dependent pressure drop is small. The simplest way to avoid this risk is to decrease the control valve opening (e.g. 80÷90%), what will raise the characteristic curve of the line and move it within the appropriate operating field. In this diagram, the maximum allowable flow rate at 100% opening is about 2.0 l/s and can be increased up to about 2.8 l/s with an appropriate closure of the valve.

Finally, a long-time operation in the light-blue area on the left of the appropriate field is also to avoid, since it would increase the risk of pump overheating pump and, if the pump is large, would cause wrong forces on pump bearings. For this reason, a minimum flow must be guaranteed. According to the pump manufacturer, a minimum of 0.2 l/s is acceptable for some hours.

In synthesis, with a good regulation of pump and control valve, it is possible to supply the network at feed-in flows ranging from 0.2 to about 2.8 l/s (i.e. about 1÷14). It is a flow range much higher than what a single solar circuit pump without control valve would enable.

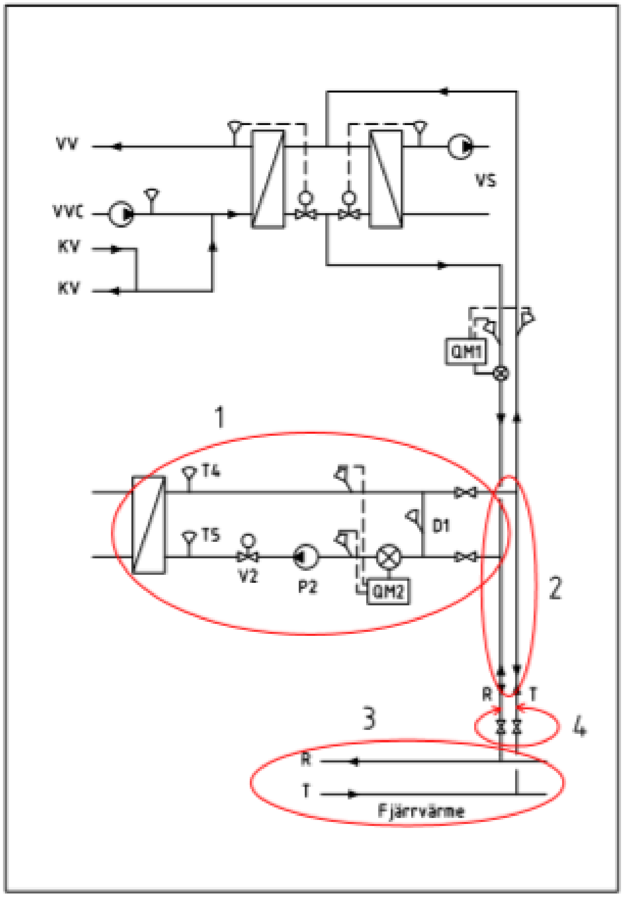

Figure 6. Pressure head components of a R/S feed-in scheme (four red circles)

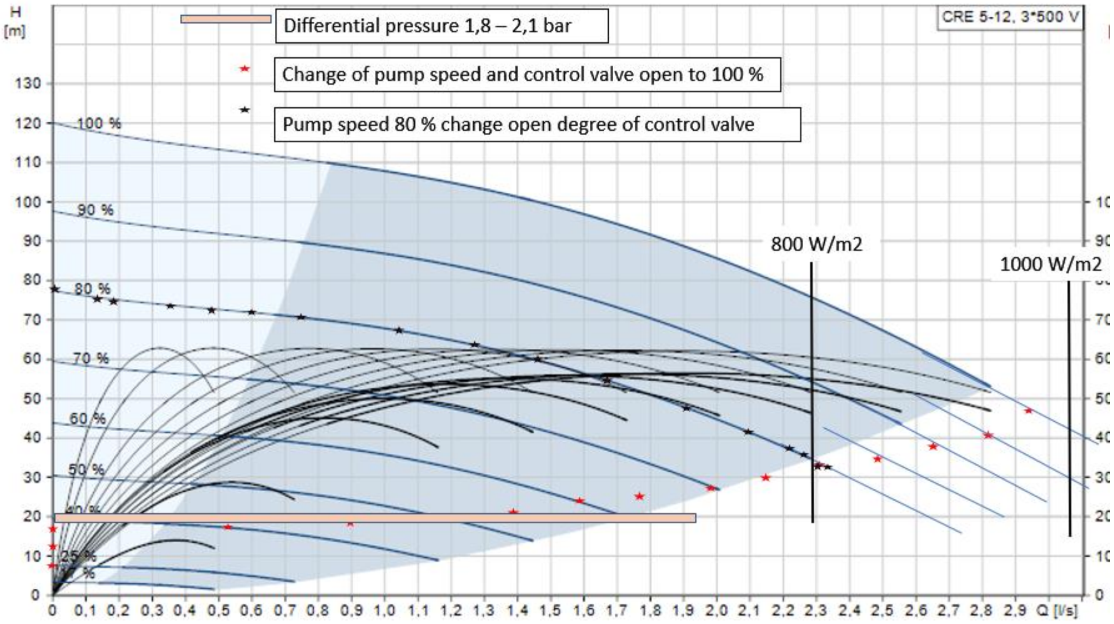

Figure 7. Characteristic curves of a feed-in pump at different speeds and appropriate operating field (blue area)

Control in the R/S scheme

In the R/S scheme, the control system must guarantee that the feed-in temperature is at the assigned set-point. In theory, a variable-speed pump and a temperature sensor are enough to accomplish this task: the pump adjusts the speed according to the offset between set-point and measure, so that the set-point is maintained. This is the so-called flow-controlled feed-in: the temperature is controlled acting on the flow. However, as highlighted in the previous paragraph, it is usually better adding a control valve to enlarge the operating range of the system as well as to increase the control efficiency. In fact, at low flow rates the characteristic curves of the pump and of the line are typically flat (see Figure 7), so that changes of the differential pressure disturb significantly the flow if it is regulated just through the pump speed. A recommended scheme for R/S feed-in is represented in Figure 8, in which P2 and V2 are respectively the feed-in pump and the control valve. At low flow rates, the pump must simply enable the feed-in by ensuring a pressure head above the differential pressure D1, while the flow rate is controlled by the control valve. In general, higher pressure heads and smaller flow rates (i.e. in other worlds smaller ST systems) enable a more accurate control [4].

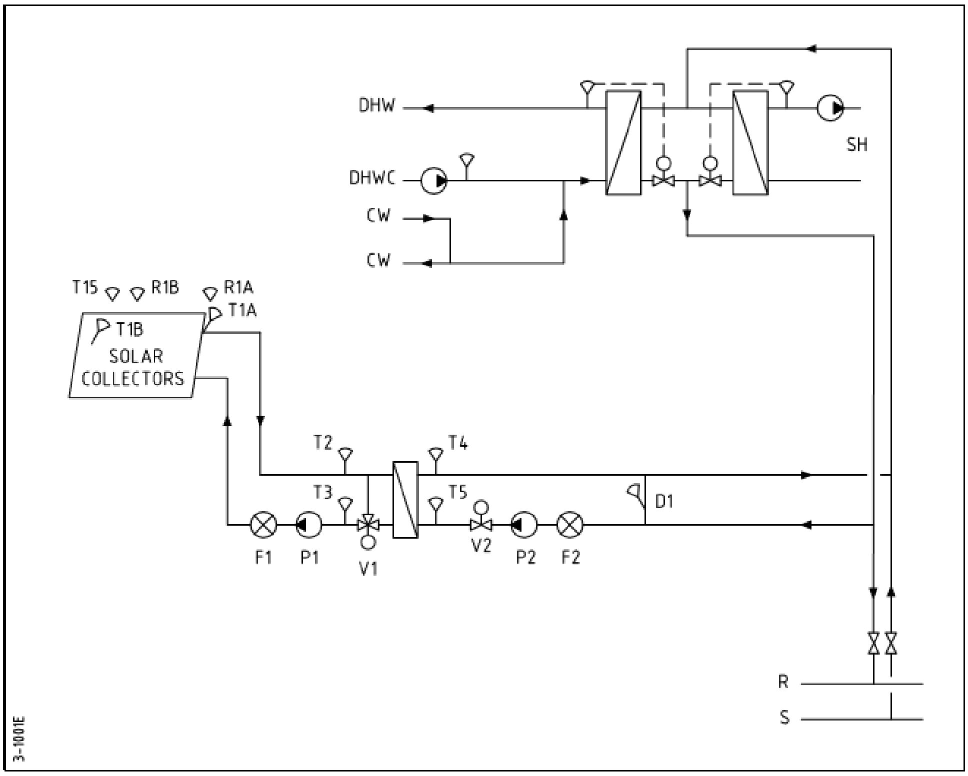

Figure 8. Flow-controlled decentral R/S feed-in scheme (not all details reported)

An alternative control scheme is the so-called temperature-controlled feed-in, represented in Figure 9. This scheme considers also the control of the temperature at the solar station inlet (T5): a bypass acting as a shunt and controlled through the valve V4 allows maintaining T5 at the assigned set-point. The feed-in temperature (T4) is controlled like in the flow-controlled feed-in, i.e. through the pump P2 and the control valve V2. In general, this scheme is recommended only when the decentral generation system sets a constant raise of the return temperature (such as in heat pumps), what usually is not the case in the return-to-supply feed-in of ST heat. Therefore, the flow-controlled scheme should be preferred for ST.

A reasonable application of the temperature-controlled feed-in can be for example for decentral chillers producing cold for district cooling systems. In this case, the solar heat-exchanger in Figure 9 is replaced by the evaporator of the cooling machine. With the help of the valve V4, the control of the inlet temperature becomes easier than in a flow-controlled feed-in.

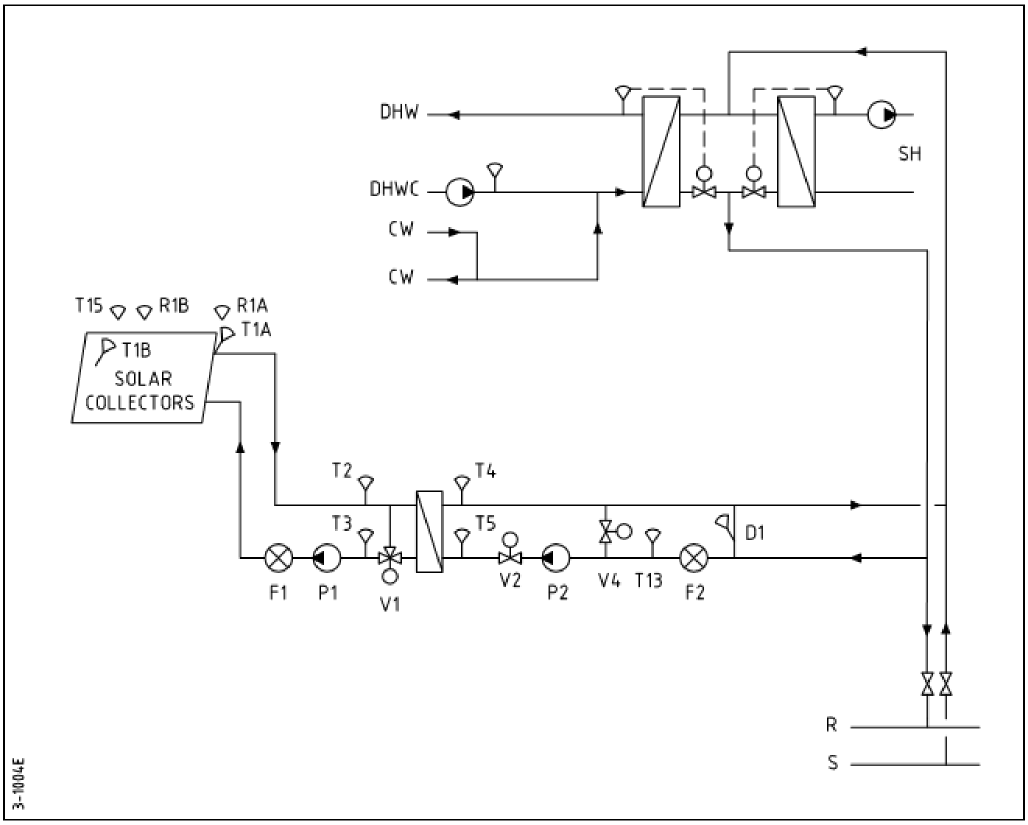

Figure 9. Temperature-controlled decentral R/S feed-in scheme (not all details reported)

Concepts for integration of decentral ST on the secondary side

When ST is connected only to the secondary side, no feed-in occurs. If the building is connected to a DH system, ST is normally used to preheat domestic hot water (DHW) in series with the substation and to cover the losses of the circulation system. A storage is necessary to prevent stagnation (solutions without storage are reasonable just for very small systems, below 0,5 m² solar collectors per 100 m² apartment area). An example is illustrated in Figure 10, where heat exchangers are inside the storage both on the ST and on the DHW side. However, external heat exchangers are also possible on both sides. This option is represented in Figure 11, which also shows a DHW station with two steps. The two-step is a concept implementing a cascade connection: the primary return from the SH heat exchanger is used to preheat the DHW in a first step upstream of the preheating with ST. This concept can be advantageous to improve the cooling of the primary side when the temperature or flow demand for space heating (SH) is high, such as in old buildings with low SH standards.

A parallel connection of ST and DH is not recommended, as it would need higher operating temperatures of ST system and storage (i.e. higher losses) to meet the requirements for the hygienic DHW preparation.

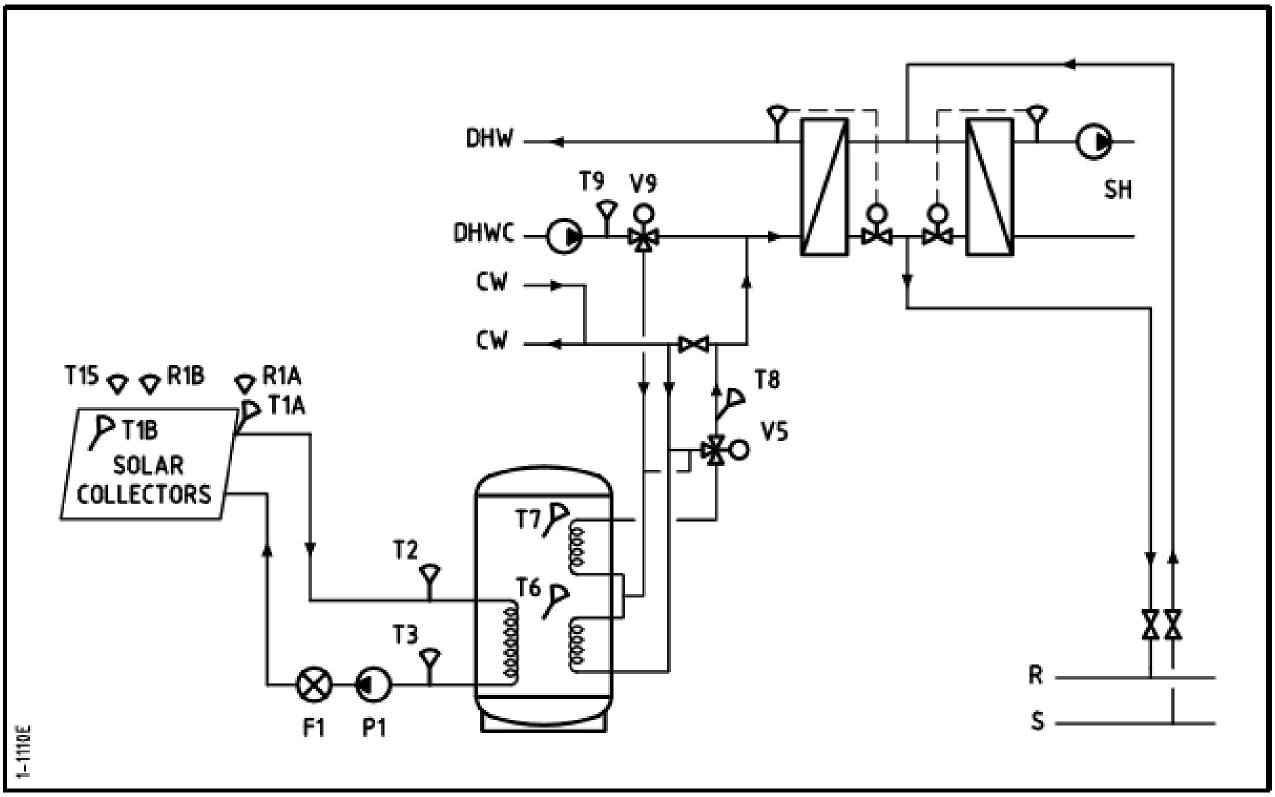

Figure 10. Secondary-side connection of ST in series with a single-step DHW station (not all details reported)

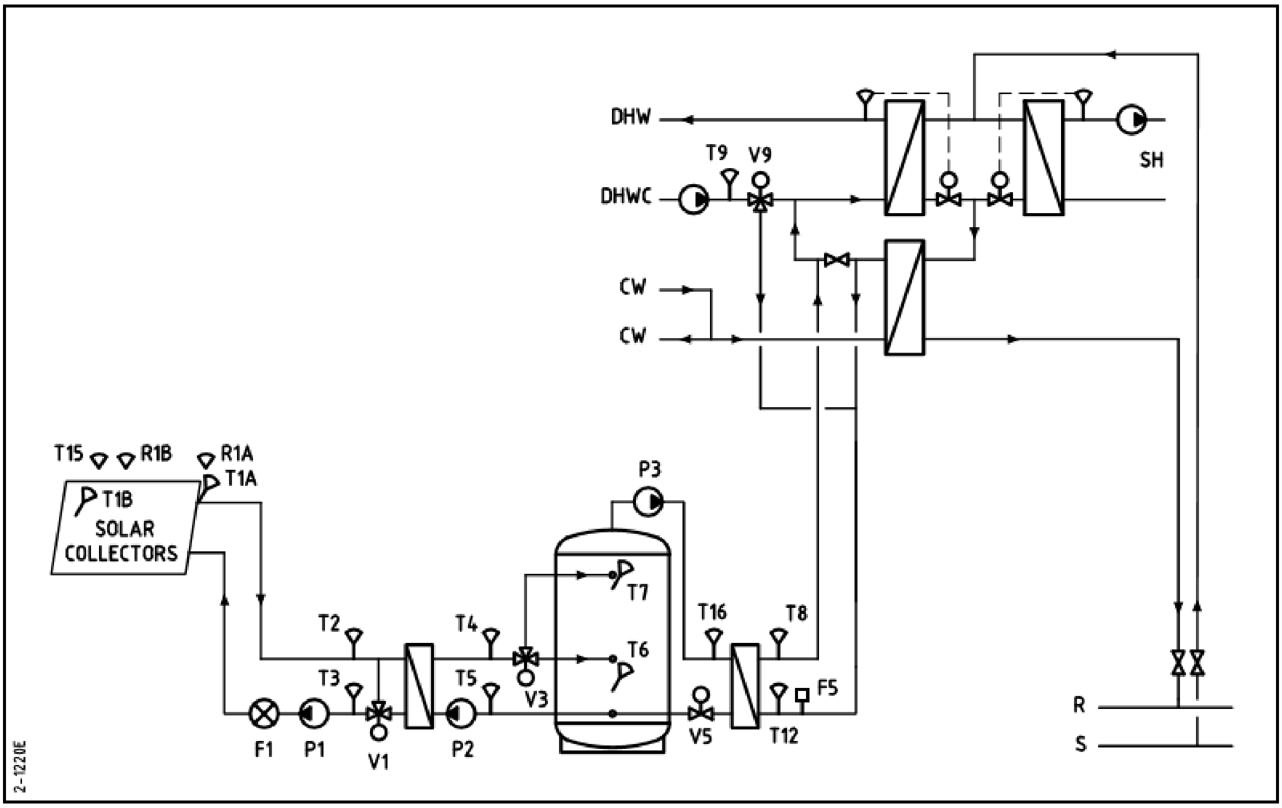

Figure 11. Secondary-side connection of ST in series with a two-step DHW station (not all details reported)

The connection of ST to the space heating system is very uncommon, since there is typically no or low demand for SH when the ST production is high. Such a connection is reasonable just when the ST system is particularly large. The connection with SH can be direct (Figure 12) or indirect (Figure 13). However, feed-in is a more recommended alternative, which additionally allows the use of smaller (or no) storages.

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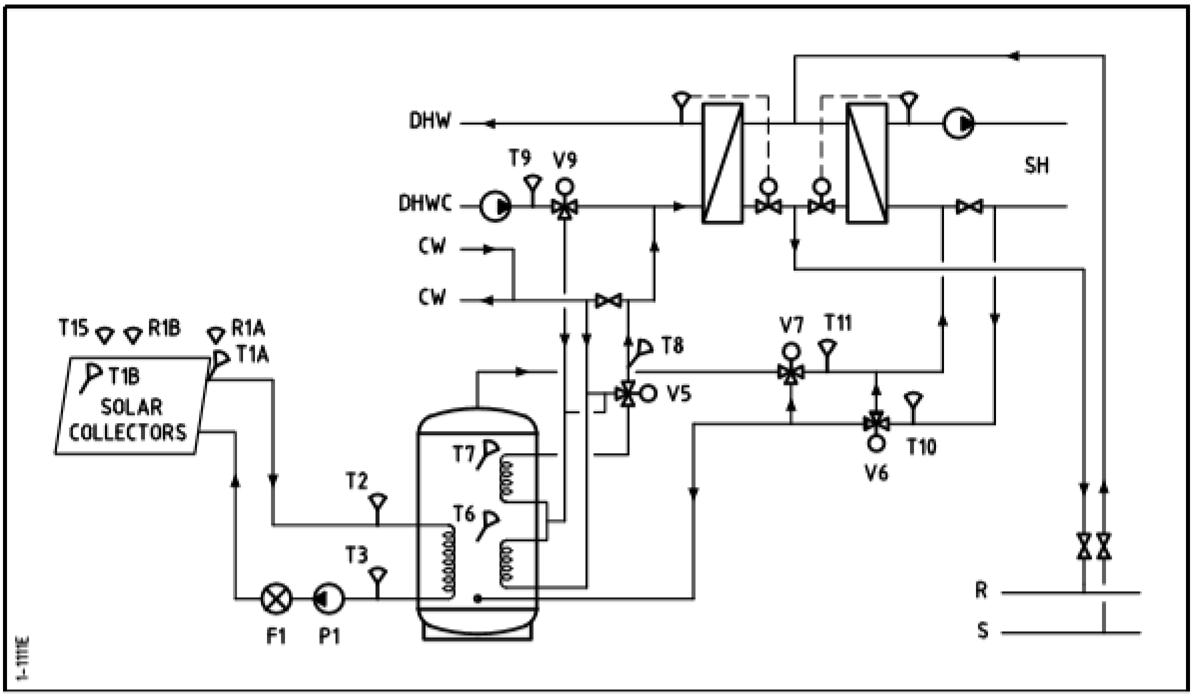

Figure 12. Secondary-side connection of ST in series with the DHW station and direct SH return preheating (not all details reported)

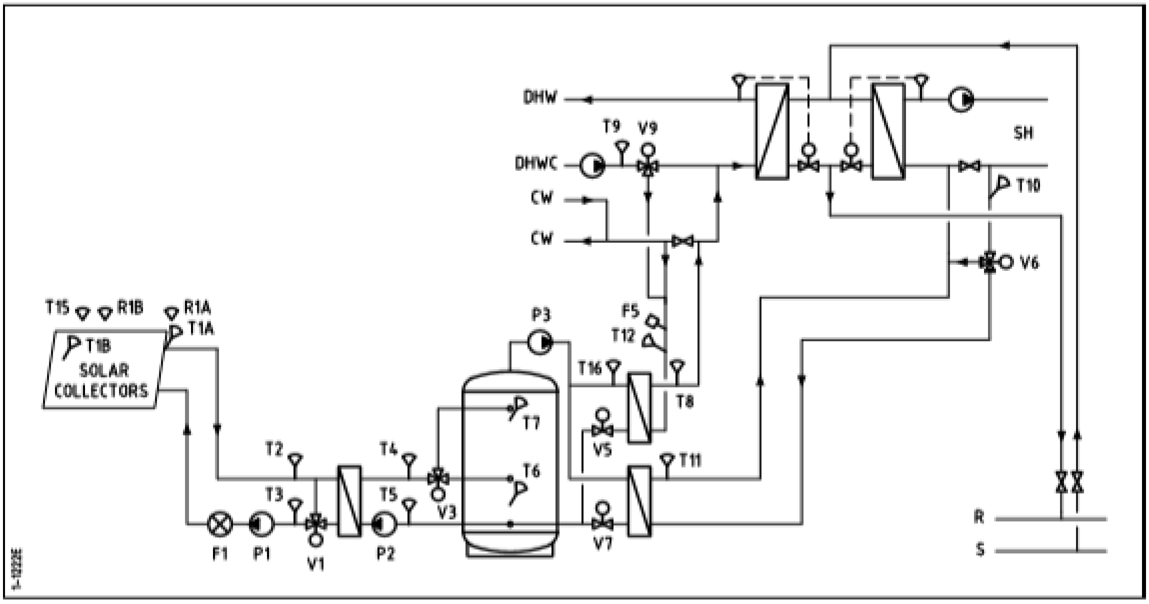

Figure 13. Secondary-side connection of ST in series with the DHW station and indirect SH return preheating (not all details reported)

Best-practice examples of decentral ST integration in DH systems

Graz: Wasserwerke Andritz (Austria)

Wasserwerke Andritz is the largest ground-mounted collector array in Austria (3855 m^2), supplying domestic hot water and space heating for a nearby office building and/or feeding into the district heating grid of Graz. The solar collector installation (Figure 14) was built between February and June 2009 on the premises of the water utility Graz AG. The company was faced with increasing prices for electricity, and therefore decided to adopt alternative sources of heat in an economic and ecological way. Since the existing system had reached the limits of its lifetime, and had become relatively inefficient compared with current technologies, the company decided to increase the system performance to provide the future energy supply by combining solar thermal energy, district heating, and a heat pump.

Figure 14. ST collector field at Wasserwerke Andritz in Graz (Austria)

The integration concept (Figure 15) intends to maximize the direct usage of heat from ST. A heat pump increases the direct usage further. The heat excess is fed into the storage or, if it is fully charged, into the network through a dedicated connection pipe with a feed-in pump provided with inverter.

Technical data:

- DH network demand: 1100 GWh/a (plus losses)
- DH network operating temperatures:
    - Supply 75÷120 °C

  - Return ~60 °C
- Collector area: 3855 m^2 flat
- ST production: 1620 MWh/a
  - 400 MWh/a direct use
  - 1220 MWh/a feed-in
- Supply temperature: min. 75 °C
- Storage: 64 m3
- Feed-in scheme: return-to-supply

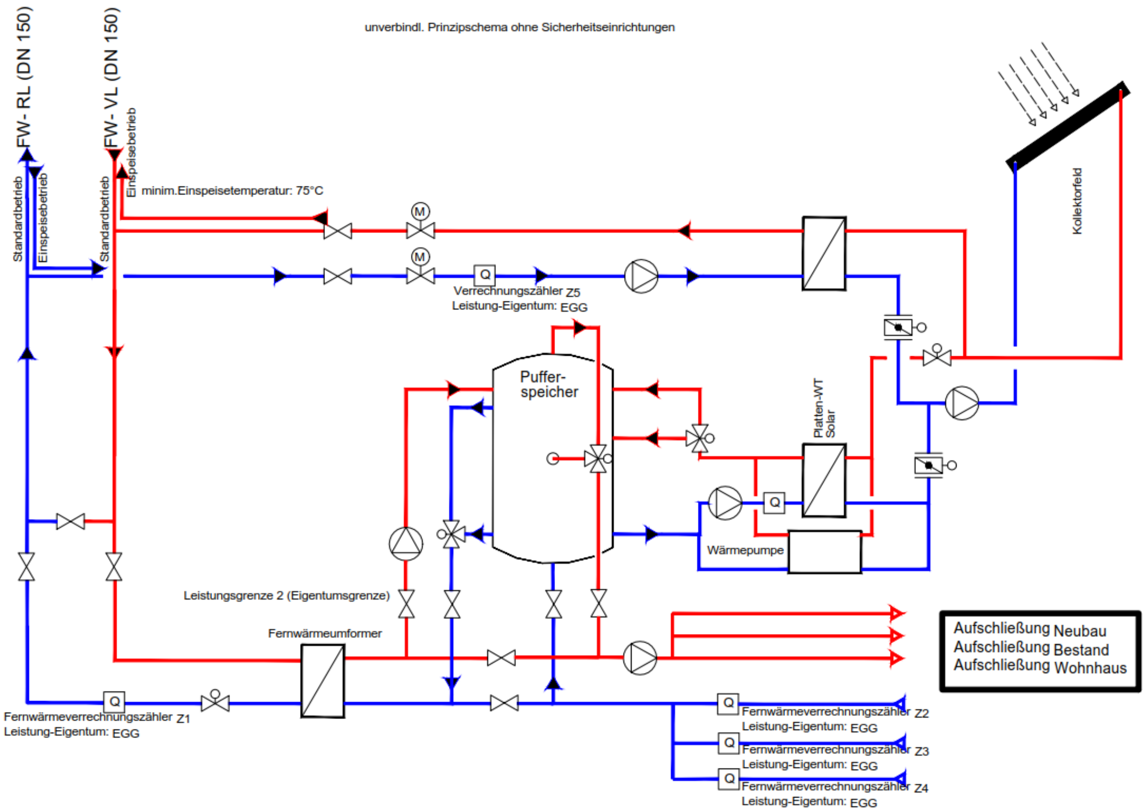

Figure 15. Feed-in hydraulics of decentral ST heat at Wasserwerke Andritz (Source: SOLID)

Graz: Berlinerring (Austria)

Berlinerring is a residencial complex with 25 houses and 756 flats in Graz-Ragnitz. A local DH network receives heat from the main DH network of Graz and is operated at lower temperatures. Flat plate collectors are mounted on the roof of 6 multi-family buildings (Figure 16). The ST loop has two parallel stations (

Figure 17): one to supply the building (connection return-to-return) and one to supply the local network (connection return-to-supply). A 3-way valve regulates the flow distribution between the two solar stations. In summer, ST production covers almost the entire demand of the local network.

Figure 16. Rooftop-mounted ST collector field in Berlinerring (Graz)

Technical data:

- Local DH network return temperature: 40÷50 °C
- Collector area: 2417 m^2 flat on the roof of 6 multi-family buildings
- ST production: 1000 MWh/a
- Storage: 60 m^3
- Feed-in scheme: return-to-supply

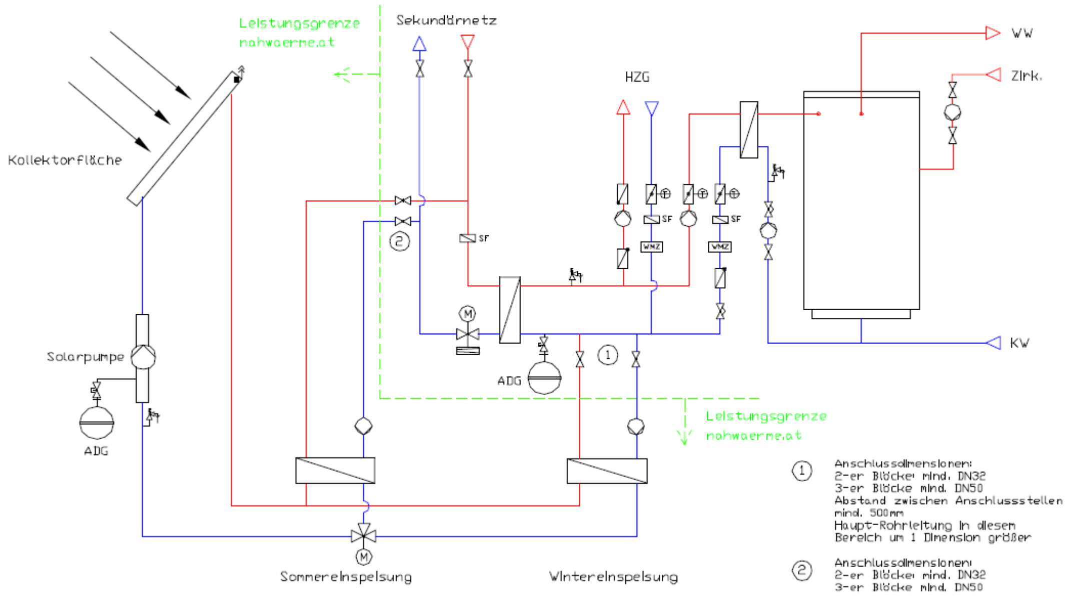

Figure 17. Feed-in hydraulics of decentral ST heat in Berlinerring (Source: SOLID)

Ystad (Sweden)

An example of decentral ST integration with 100% feed-in is the one realized in Ystad (Figure 18). The plant was commissioned in 2017. The collector field consists of 36 Savosolar Oyj collectors distributed in 6 rows for a total active area of 534 m^2. The station and other component were delivered by Absolicon Solar Collector AB. The feed-in scheme can by switched between R/R and R/S (Figure 19).

Figure 18. Rooftop-mounted ST collector field Ystad (Sweden)

Technical data:

- DH network demand: 140 GWh/a (plus losses)
- DH network supply temperature: 75 °C
- Collector area: 534 m^2 flat
- ST feed-in: 250 MWh/a or 470 kWh/m^2, year (37 % of irradiated)
- Feed-in temperature: 75 °C (in R/S-mode)
- Storage: none but in the DH-network
- Feed-in scheme: Return-to-return and return-to-supply

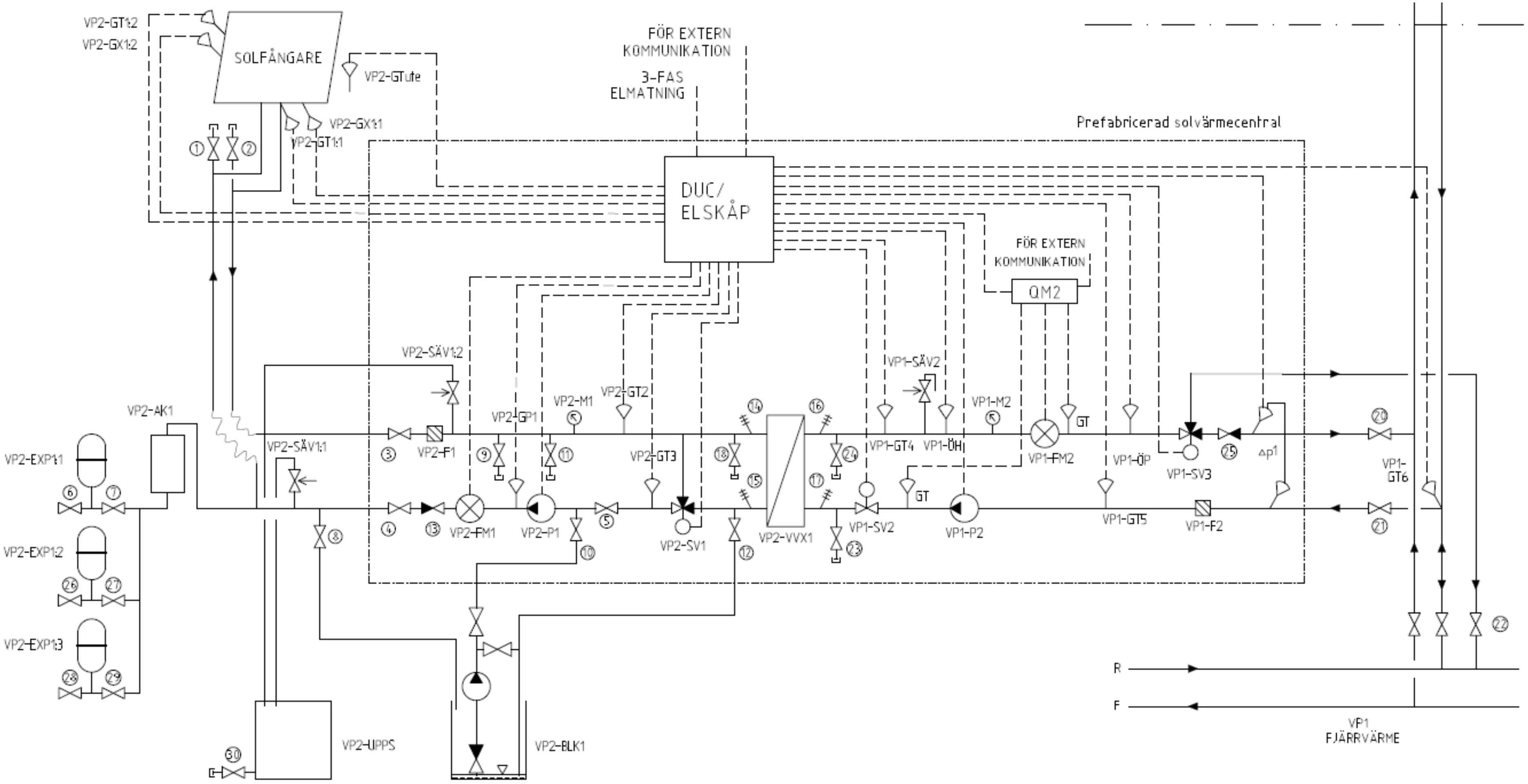

Figure 19. Feed-in hydraulics of decentral ST heat Ystad (Source: Ystad Energi and Energianalys AB)

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