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

A-D4.2 Control of DHC networks and Reduction of the operating temperatures in DH systems

IEA SHC FACT SHEET 55.A-D4.2

Subject:	Control of DHC networks and Reduction of the operating temperatures in DH systems
Description:	Overview on different approaches for the control of the heat distribution networks in case of the integration of large-scale solar thermal systems, and different possibilities for the reduction of the operating temperatures in DH systems.
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Introduction

The present fact sheet focuses on the control of heat distribution networks, in particular district heating (DH) networks, and on measures for reducing the operating temperatures in existing systems. Lower network temperatures can be reached through optimization measures both on the controller and on the infrastructure, and they are essential to increase the operating efficiency and flexibility of the DH system, in particular in presence of solar thermal (ST) and low-temperature sources.

Control of DHC networks

The control of large-scale solar thermal systems and heating grids - respectively hybrid energy systems - in which they are embedded, goes along with several control tasks, which are carried out in different control layers. At a higher level, supervisory controllers, often referred to as energy management systems, decide on the operating mode of the different plants and components, and provide the reference signals for their controllers. These modes of operation of the different plants and components are then carried out by the respective controllers at plant and component level, and by those responsible for the operation of the district heating network. The control of large-scale solar thermal systems thus can be divided into the following 3 main categories:

1. Supervisory control (energy management systems), which is the focus of IEA SHC FACT SHEET 55.A-D4.1.
2. **Control of heat distribution networks, which will be the focus of this FACT SHEET, IEA SHC FACT SHEET 55.A-D4.2.**
3. Control strategies for the integrated plants and components, i.e. the actual solar plant but possibly also heat pumping systems or other plants and components. The control of large-scale solar plants is the focus of IEA SHC FACT SHEET 55.B-D3.1.

The control of heat distribution networks must on the one hand adjust the feed temperatures of the different producers, and on the other hand control the pressure and mass flow conditions accordingly to the load situation. Both tasks are displayed in the two main sections of the chapter on the *Control of DHC networks*.

Reduction of the operating temperatures in DH systems

Temperature reduction plays a key-role in increasing the energy efficiency of existing European DH systems and, most importantly, in allowing a higher and more cost-efficient integration of ST and other sustainable low-temperature sources. Solutions to reduce the network temperatures are developed and demonstrated in the H2020 project TEMPO. The project demonstrator representing an existing urban DH system is the one of Brescia (Italy).

Another important aspect to consider in temperature reduction is the presence of technical, economical, and legal barriers. These can often hamper the necessary investments or even make identifying the most efficient optimization measures difficult. To overcome those barriers, innovative business models for DH utilities have been investigated, developed, and implemented in the last years. This fact sheet reports a summary of an analysis on this topic performed within the Austrian project T2LowEx [1].

Content

Control of DHC networks

The control of the heat distribution networks in general must fulfill the following two main tasks [2]:

1. Adjustment of the feed temperature to the load situation to keep the heat losses small during times of low load and ensure supply during times of high load.
2. Adjust of the pressure and mass flow conditions, i.e. essentially the speed of the pump(s), according to the load situation in the network.

Adjustment of the feed temperature

The feed temperature T_{feed} is typically adjusted according to the ambient temperature $T_{ambient}$ to the current load situation, since the demanded heat correlates with the ambient temperature. The adjustment leads to a compromise between pumping costs and heat losses. This is typically done according to a simple, piecewise affine heating curve as schematically outlined in Figure 1.

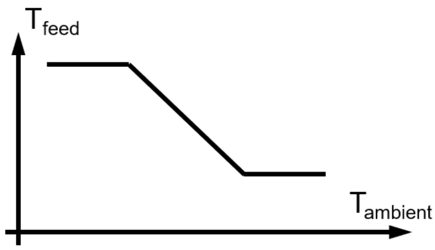

Figure 1: Typical adjustment of the feed temperature to the ambient temperature

This procedure also remains the same with multiple suppliers, however, they often have individual curves accounting for the favored temperature distribution along the network. In case of different owners (cross-ownership energy systems) the feed temperatures and the allowed range of variation are specified in corresponding contracts.

The control of the feed temperature is typically carried out by simple PID controllers acting on the actuators. For conventional suppliers this are often solely three-way-valves. Solar thermal plants are typically integrated via plate heat exchangers. In this case the PID controllers normally act on the pumps on the producer side, aiming to minimize the terminal temperature differences over the heat exchangers to maximize the efficiency.

In many cases the feed temperature is additionally increased prior to periodical load peaks, e.g. in the morning hours, to temporarily increase to maximum load available for the consumers.

Current research also investigates possibilities to jointly determine the optimal feed temperatures and the optimal operating mode of the different producers, and in many cases also consumers (demand side management), by optimization-based, predictive supervisory controllers. Possible approaches for this are discussed in FACT SHEET 55.A-D4.1 *Supervisory control of large-scale solar thermal systems*. However, these investigations are at a very early stage of research at the time the fact sheet was created. The key problem is the uncertainty of the demand of individual consumers and the need to have a good understanding of when heat from which producer will reach which part of the network. If demand is not mapped correctly to individual branches of the network, some branches of the network might be heated up before a local drop in demand, while other branches might still have to be heated up at the same time the corresponding demand is already peaking. This results in both heating losses in the one branch and high power and pumping demand in the other. Thus, more intelligent control algorithms for adjusting the different producers and possibly consumers (demand side management) could also lead to less efficiency than a simpler approach, if it is not thought through to the end.

Adjustment of the pressure and mass flow conditions

To adjust the distribution of the heat in the DHC network to the current load situation the pressure and mass flow conditions in the network need to be adjusted properly. This is done by adjusting the rotational speed of the feeding pump, respectively feeding pumps in the case of multiple feeding points. Depending on characteristics, size and age of the DHC network different strategies for controlling the pressure and mass flow conditions are applied. However, in the first step these strategies depend on the feeding situation, i.e. whether the network is supplied via one single feeding point or via multiple feeding points.

Supply via one single feeding point

In very old, and typically rather small, DHC networks it could be the case, that the networks are still operated with constant rotational speed of the pumps. However, this strategy cannot be recommended, since it is very inefficient and thus should also not be discussed in more detail.

State of the art is to reduce the rotational speed of the feeding pump (see Figure 2) so far that the demand can still be met at every position of the network, i.e. the pumping costs and heat losses due to overflow from feed to return are as small as possible. This is done in two different ways, by controlling the feeding pump according to either the differential pressure at neuralgic points of the network or, if this information is available, to the valve positions of the transfer stations of the consumers.

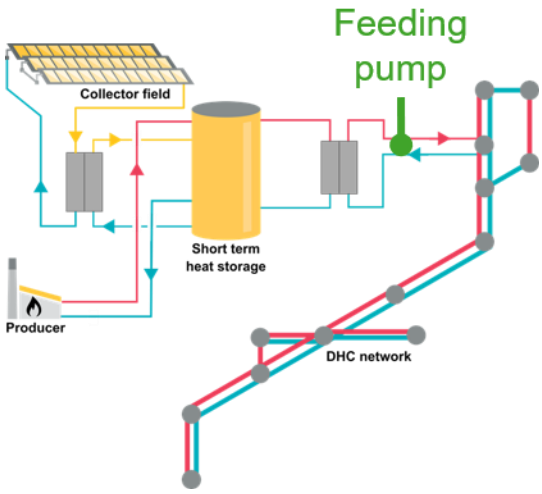

Figure 2: Scheme of a DH network with one single feeding point indicating the position of the feeding pump

Control of the feeding pump according to the differential pressure at neuralgic points of the network

This strategy has the main advantage of getting along with only a few differential pressure measurement signals, however, the measurements used need to be chosen well. This could be rather simple for networks with low complexity. For more complex networks a good knowledge of the network, preferably supported by at least static network simulations for different operating situations, is necessary. Furthermore, the *weakest* point of the network varies according to the load situation, thus the control strategy needs to account for this appropriately as well. However, in most cases the load situation does not vary too quickly, i.e. to always just use the currently weakest point is enough in most of the cases.

Control of the feeding pump according to the valve positions of the transfer stations

In this case the feeding pump is controlled in such a way that the valve of each transfer station has at least a small reserve to its maximum opening position, i.e. so that each consumer gets the heat demanded. However, the strategy requires a high degree of digitalization, each transfer station must be equipped with an appropriate data connection. This is by far not the case in all DHC networks. Even if the connection is available, many operators stick to measuring the differential pressure at neuralgic points or go back to that strategy, since the data connection to the transfer stations often turned out to not be sufficiently robust.

Supply via multiple feeding points

In DHC networks with multiple feeding points the control strategies for adjusting the pressure and mass flow conditions are basically manifold.

Large DHC networks typically have numerous pumping stations, which inline impose a pressure increase in the feed or return flow. The exact control strategy applied strongly depends on the exact network topology and therefore cannot be generalized and thus should not be discussed further, however, the pumps are typically located at critical points in the network, and their rotational speed is adjusted according to the differential pressure at specific points of the network.

In contrast to this, the feeding pumps in smaller networks are typically solely located at feeding points. In this case often only a part or even only one of the feeding pumps is controlled according to a differential pressure (or the transfer stations' valve positions), and the other feeding pumps are controlled to feed a certain mass flow. Figure 3 illustrates this exemplarily for a simple configuration with one central producer and a decentral solar thermal plant with an on-site buffer storage and on-site consumers. The feeding pump at the central producer ensures the differential pressure necessary to guarantee the supply of all consumers, i.e. it is controlled according to either the differential pressure at neuralgic points or the valve positions of the transfer stations. The pump at the decentral solar thermal plant only ensures to feed in a certain heat flow, i.e. a certain mass flow. The mass flow to be fed in is normally demanded by a higher-level supervisory controller (for details see FACT SHEET 55.A-D4.1 *Supervisory control of large-scale solar thermal systems*). In the simplest and widely spread case of decentral solar thermal plants without on-site consumers and buffer storages, the produced heat is immediately fed into the grid, i.e. the demanded mass flow is automatically fixed by the current heat produced, return temperature and desired feed temperature.

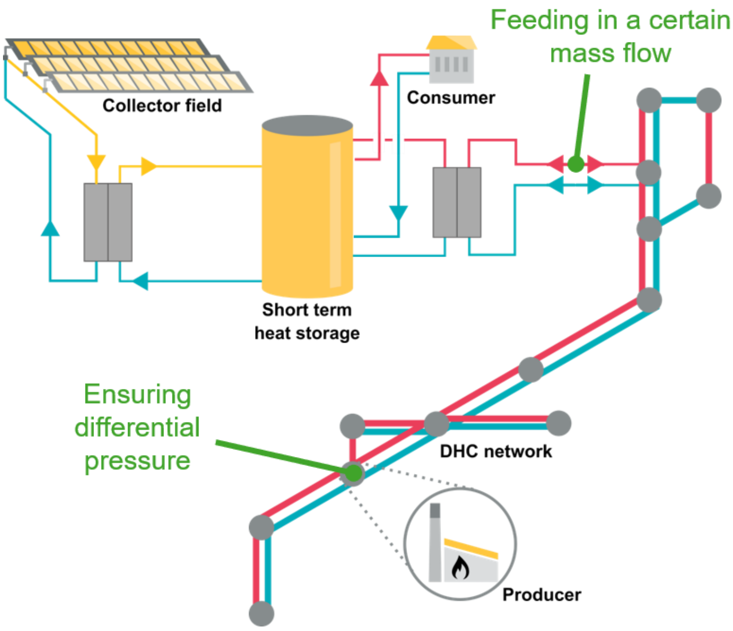

Figure 3: Scheme of a DH network with one decentral feeding point

While ensuring an appropriate differential pressure is rather simple from a control perspective, controlling the mass flow to be fed into the grid at the decentral feeding point is more challenging. This is due to the variations of the differential pressure on the feeding point. There already is a differential pressure between the feed and the return line, which significantly varies over time according to the variations in heat consumption. Thus, the pump needs to generate a higher pressure increase to cause a certain mass flow. Second, the required mass flow varies significantly. Thus, the mass flow and pressure conditions need to be variable in a very large operating range. This cannot be covered solely by a pump. It is necessary to use a comparatively strong pump in series with a 2-way-valve and apply an appropriate control strategy to the two actuators. First, the pump always needs to provide a minimal pressure head, thus have a minimal rotational speed. However, the pump characteristics in this operating range is typically rather flat, making the control of the mass flow by varying the rotational speed of the pump very difficult. Thus, the control of the mass flow is carried out by adjusting the valve position for lower mass flows. From a certain valve position on, typically less than 100%, the valve position is kept constant, and the rotational speed of the pump is used to control the mass flow. The control of the mass flow is thus carried out by adjusting a surplus of the rotational speed of the pump, which is added to its minimal value ensuring the minimal pressure increase. However, this minimal value also needs to be continuously adjusted according to the differential pressure between feed and return line. Typically, this is done by simple PID controllers in a cascadic control structure, with a much slower controller for the adjustment of the minimal value in the outer loop, and an appropriate strategy for switching between the two actuators in the inner loop. A more detailed discussion of this strategy and comparable control strategies for different feeding regimes, i.e. not return-feed supply but, for example, return-return supply, are given in [3, 4].

Reduction of the operating temperatures in DH systems

As reported in [2], the benefits of lower temperatures are:

- Higher efficiencies in the heat distribution (current networks are affected by rather high thermal losses, typically 8-15% in municipal systems and increasing up to 35% in low-density areas)
- Higher efficiencies in the power generation from steam-based CHP units
- New opportunities to diversify the heat generation portfolio, since locally available low-temperature sources (e.g. waste heat, solar thermal, geothermal, flue-gas condensation) can be integrated in a more cost-efficient way
- Increased capacities in water-based heat storages

These advantages are expected to significantly increase the environmental sustainability as well as the profitability and competitiveness of European DH.

The main technical barriers to lower network temperatures typically lie on the secondary side. In fact:

- The supply temperature must satisfy the requirements of the building heating systems
- The cooling of the primary-side water in the substations is in the power of the users, so that the network operator has no possibility to act on that without the user collaboration

As reported in [1], "*typical measures to allow a colder supply consist in refurbishing the building installations, e.g. by placing larger or additional radiators, by switching to floor-heating, by using instantaneous heat exchangers for domestic hot-water preparation or booster heat pumps. However, if not all the connected buildings are apt to receive water at lower temperature, the network supply temperature cannot be reduced. On the contrary, any user improving the performance of his substation can give his own contribute in lowering the network return temperature. Improving the substation performances is particularly important as high return temperatures, besides increasing the thermal losses of the return line, force the system to operate at higher flow rates or higher supply temperatures to satisfy the same heat demand. Then, lower return temperatures not only improve the network efficiency but also unlock flexibility*."

Experience from the H2020-TEMPO demonstration project in Brescia (Italy)

The DH system of Brescia, owned and operated by A2A Calore e Servizi, started operating in 1972 and has grown in the years hosting technologies of the 2nd and 3rd generation. Today, it represents the largest DH system in Italy, with more than 1 TWh annual supply and covering about 70% of the town heat demand. More than 60% of the heat is produced by a waste-to-energy plant.

The supply temperature is in summer 80-90 °C and in winter can reach 130 °C. The return temperature is about 60 °C. Within the H2020 project TEMPO, a peripheral branch of the network was selected to demonstrate a local reduction of the operating temperatures. The site (Figure 4) includes 35 customers with 1 large multi-family house (MFH) and 34 single-family houses (SFH), for a total contract capacity of about 700 kW. Close to the MFH were old dismissed gas boilers (in the blue circle).

Figure 4. Demo site of the H2020 project TEMPO in Brescia (Source: [5])

Those boilers were removed, with consequent requalification of the site, and replaced with a container hosting a supply-to-return mixing station (Figure 5). The construction included:

- a new trench (the low-T side, hydraulically decoupled from the main network);
- a lamination valve to enable mixing of supply and return (in a ratio depending on the ambient T) to get a colder supply on the low-T side;
- a feed pump with inverter to maintain the differential pressure;
- a bypass to secure the heat supply in case of any failure.

Additional instrumentation was added for measurement (e.g. heat meters, indoor-T sensors, etc.) and for data transmission to a cloud, with the purpose of monitoring and of enabling a smart control from remote.

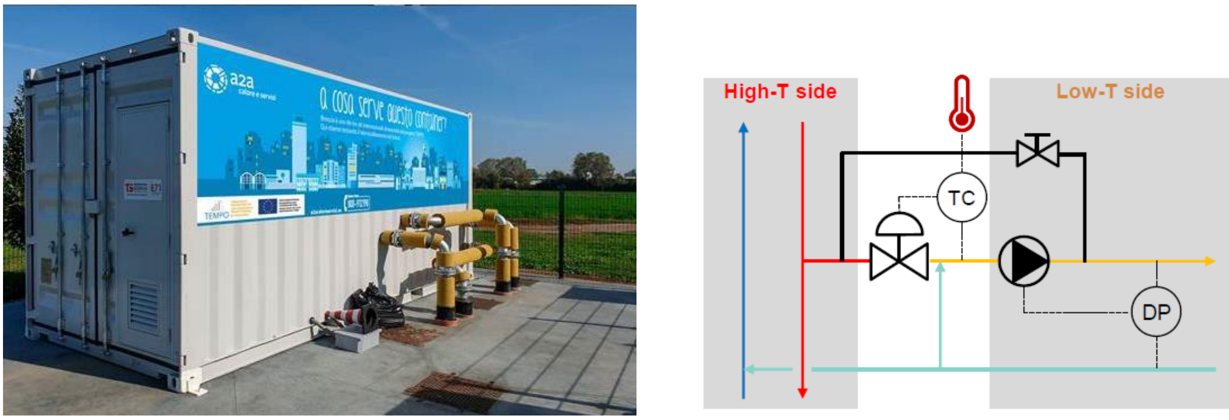

Figure 5. Supply-to-return mixing station: external view and simplified scheme (Source: [6])

During the first demonstration phase, performed in the heating season 2019-2020, the local supply temperature was decreased without significant issues to values below 90 °C, while the remaining network continued operating at the usual 115-120 °C (Figure 6). When the temperature reduction started (on January 14th, 2020) the flow showed a sudden increase.

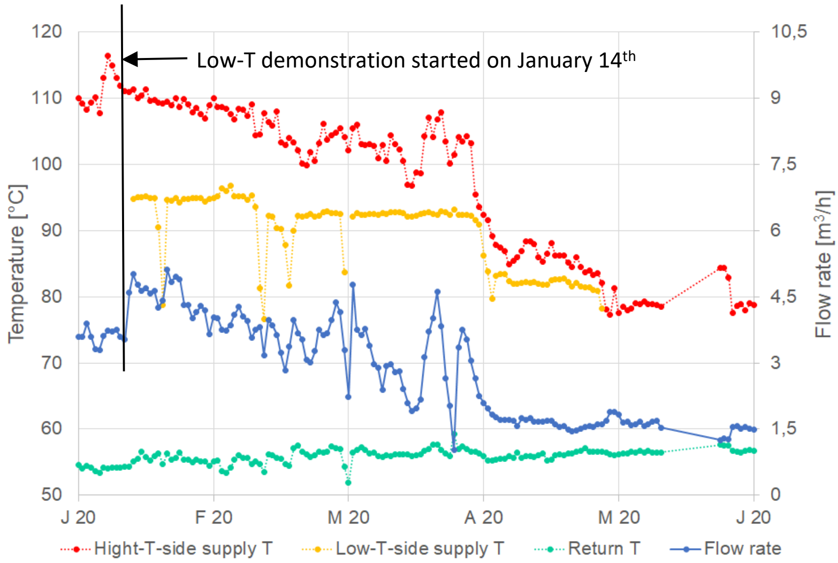

Figure 6. Monitoring data in the first half of 2020, daily averages (Source: [6])

An additional step towards lower temperatures (extended also on the return side) is expected in the heating season 2020-2021 with the implementation of the smart control and of building-side optimization measures. In a future phase beyond TEMPO scope it will be possible to consider a replication and an extension of the temperature reduction as well as the integration of locally available no- or low-carbon low-T sources.

The lessons learned so far are:

- the mixing station operates well and reducing the site supply temperature by 15 °C is technically feasible;
- when the supply temperature was lowered, the flow increased (as well as slightly the return temperature) because of the control at the customer substations;
- the efficiency measures revealed to be also an opportunity for the site requalification;
- customer engagement was an important and successful step for the acceptance of lower supply temperatures and for the sensor installation in the buildings (it included delivery of letters, flyers, and a public assembly with customers and local authorities).

Incentivizing lower return temperatures

Elaborating solutions to incentivize a substantial temperature reduction in existing DH systems is part of the ongoing Austrian project T2LowEx. The first results are reported in the paper [1]. Here, information collected through the review of international success stories and through interviews with stakeholders are used to derive recommendations for business models and propose new ideas for Austrian DH utilities, though the replicability in other countries is not excluded. Particular focus is paid on solutions incentivizing the deep implementation of measures on the demand side to reduce the network return temperatures.

Table 1 gives an overview of the most important barriers to lower network temperatures in existing systems.

Table 1. Comparison of reference and trans-sectoral system (Source: [1])

Barrier	Description
Technical	Building installations are not conceived for low temperatures Faults on secondary side increase the return temperature DH utilities lack of monitoring data for efficient fault detection methods
Economic	Low availability of resources to optimize the DH system
Social	Higher heat prices to finance system optimization reduce public acceptance of DH
Legal	Landlords are not allowed to charge optimization expenses on tenants

The business models to address those barriers and incentivize, in particular, lower return temperatures are elaborated with the intention to act on three levels:

- Engagement of customers in fault detection and in temperature reduction thanks to improved relationships, extensive communication, new tariff structures, customized offers, counselling services

- Financing of fault detection and optimization measures through strategic partnerships and crowdfunding platforms
- Energy Saving Contracting, especially (but not only) to solve the split incentive issue in rental homes

Figure 7 gives an overview of the proposed concept and of the principal actors involved. "*The monetary benefits due to lower operating temperatures are supposed to return to the investors and, in accordance with the adopted motivation scheme, to the engaged customers. Investors can be the DH utility itself as well as different stakeholders, including contractors implementing energy saving measures. The invested capital is used to detect faults and optimize the system as well as, in case, to integrate new technologies for heat supply at lower temperatures. The customers, together with or alternatively to monetary investments on their installations, can support the system optimization with practical contributions (e.g. correct wrong behaviors, inform the utility about substation anomalies, allow inspections at the building installations).*" [1]

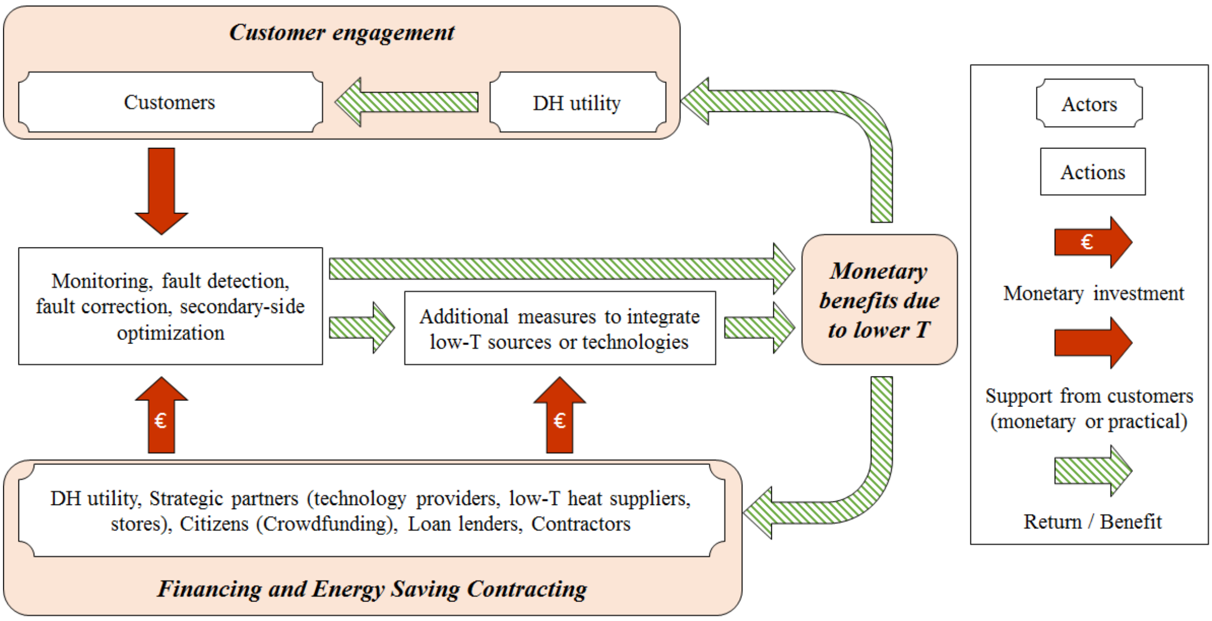

Figure 7. Overview of the concept proposed in the project T2LowEx (Source: [1])

The main target of the new business models will be to share the created value of lower system temperatures in a way incentivizing network-friendly behaviors. For the assessment of the business models, AIT developed a tool calculating economic KPIs in four different investment schemes: 1) DH utility as investor; 2) customer as investor and implementation of motivation tariff; 3) external investors (fonds, loan lending, crowdfunding); 4) energy saving contract. These schemes, with the relevant actors (customer, operator, and, accordingly, investor or contractor) and the relevant saving/investment flow, are represented in **Figure 8**

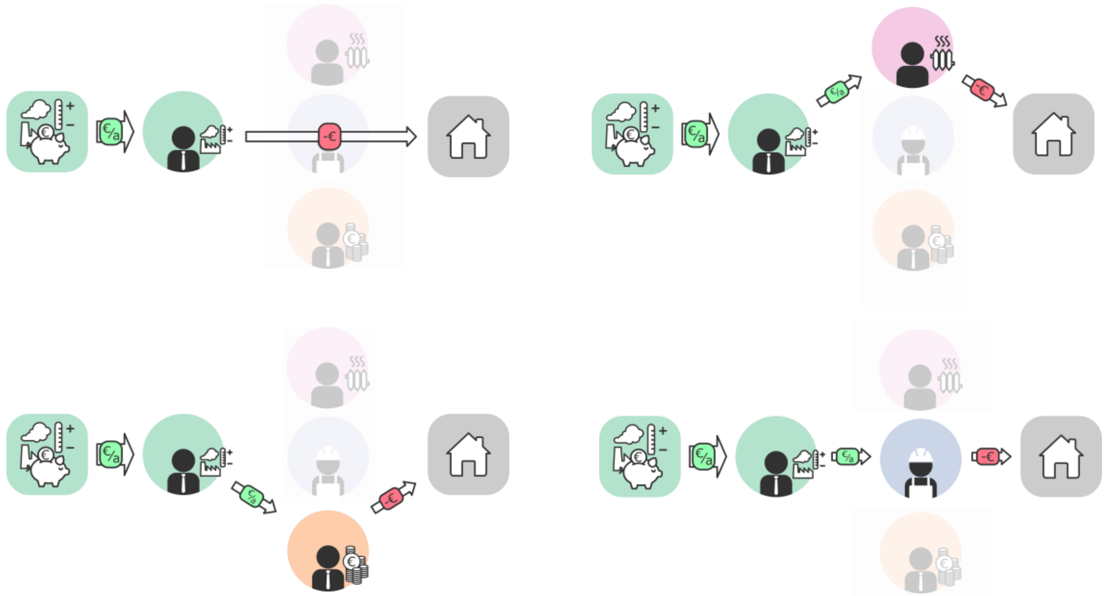

Figure 8. Overview of the proposed investment schemes (Source: AIT)

Another possibility to consider in a future work could be to increase the citizen participation through cooperatives, following the examples of Danish and German models [7] [8]. The investigation of the potential of such solutions in Austria was out of the range of this study. However, the solutions recommended here include the participation through crowdfunding platforms, which, although a phenomenon different from cooperatives, are recognized to be valuable participation tools with similar principles [9].

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