1. Design of 3FS

1.1. Introduction

Ultra-Low temperature district heating introduces multiple benefits at network level, as the reduction of heat losses and the improvement of heat generation efficiency. ULTDH also facilitates the integration of low temperatures renewable energy sources and waste heat into the district heating network. Renewable heat sources as solar thermal and heat pumps can be coupled to the district heating network and the buildings through specially designed district heating substations. During the RELaTED project, several district heating substations with multiple functionalities have been designed and demonstrated.

1.2. Summary

This report includes the activities carried out in D3.3 which regards the design of Triple Function Substations (3FS) in combination with different RELaTED technologies:

- Building Integrated Low-Temperature Solar Thermal system (BILTST)
- District Heating Reversible Heat Pump (DHRHP)
- Microbooster Heat Pump.

Several 3FSs have been evaluated and designed. Those were investigated in different versions, connection schemes configurations and operating modes depending on the district heating characteristics, the building types and the heating technologies used.

During the development of the project it was found that there is not such a single 3FS substation design, but that the unit main design characteristics depends not only on the load levels but also on the type of DH networks and the type of heating system the 3FS is placed in. The possible concept designs of the 3FS were grouped in the following case scenario:

ULTDH connected to:

- Existing buildings with:
  - DHRHP and BILTST (Demo in Taastrup (DK)
  - DHRHP (Demonstration in Taastrup (DK)
- nZEB buildings with:
  - DHW Microboosters and BILTST (Demonstration in Taastrup (DK)
  - DHW Microboosters alone (Demonstration in Taastrup (DK)

LTDH connected to:

- Existing buildings:
  - With BILTST (Demonstration in Belgrade)
  - Without BILTST (Standard case)

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System and flow diagrams for each case were proposed. In the case of a 3FS for ULTDH connected to existing buildings equipped with BILTST, a maximum of eleven possible theoretical combined operational modes were found. In this specific case a more detailed Process and Instrumentation Diagram (P&ID) was initially proposed.

Demo sites

Belgrade (Serbia). The demand specification of a Two-Function Substation (2FS) specifically adapted for the Belgrade primary school demonstration site was prepared. Control strategy and process diagrams were developed and a mechanical design was proposed. The unit is being currently built and it is expected to enter in operation before the end of Q3 2021.

Taastrup (Denmark). The demand specification for three different district heating substations was prepared. This includes process and instrumentation diagrams, flow chart, control specifications, bill of materials and mechanical design. All units were installed in Taastrup, and they are operating on the same heating grid but on alternative applications.

1.3. Triple function substation.

Several 3FS design concepts were proposed. The units have been thought for the operation with ULTDH at typical supply temperatures of 40 ºC and LTDH at supply temperatures of 60°C. The 3FSs allow for an easier integration of solar thermal and heat pumps in district heating introducing the following functionalities:

1) Extraction of heat from the district heating network (conventional). ULTDH can be used to supply space heating to the buildings and it can be utilized by the DHW Microbooster unit to produce domestic hot water. Additional heating capacity can be supplied by the BILTST or by a HP, if the demand is higher than the available solar heat production.

2) Injection of heat at high temperature to the supply line of the DH grid. When solar heat production increases above the space heating and DHW demand, heat can be supplied back to the district heating flow line, if the supply line temperature is reached.

3) Injection of heat at low temperature to the DH return line. This allows for an increase of the heat generation efficiency of the solar heating panels and heat pumps and increased exploitation of renewable energy sources, also in the case that the supply line temperature is not reached.

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1.3.1. 3FS is ULTDH in existing buildings with DHRHP and BILTST

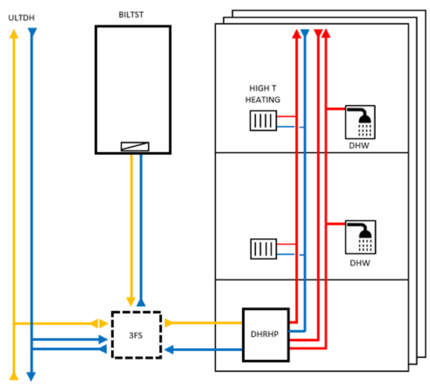
In the initial phase of the project, several unit configurations and operating functionalities were investigated. In Table 1 a summary of the conceptual proposal of a 3FS used for ULTDH in existing buildings with a DHRHP and BILTST is presented. Many more examples have been prepared and examined and compared along the project.

System and unit flow diagrams with main required components, dimensioning parameters and operating modes are introduced.

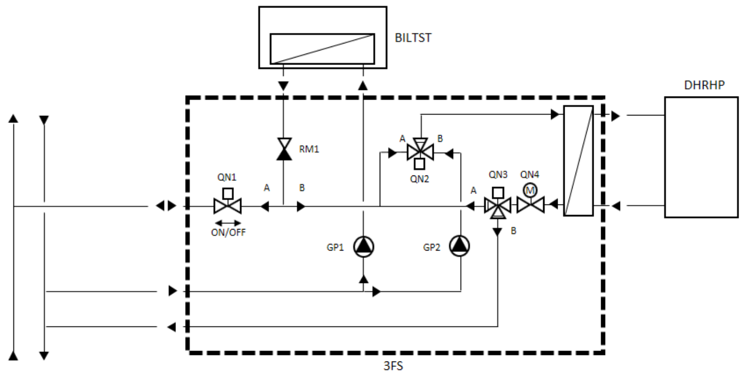
Table 1. Conceptual proposal of a 3FS used for ULTDH in existing buildings with a DHRHP and BILTST

DH NETWORK	BUILDING TYPE	SPACE HEATING	DHW	BILTST
ULTDH (45/30C)	Existing and/or cooling	DHRHP (Heat Pump)	DHRHP – (Recirc)	Yes

SYSTEM FLOW DIAGRAM



3FS flow diagram



OPERATING MODES	HP	BILTST	Dimensioning parameters			Components	
EXTRACTION	Heating	OFF	Location	T max	T nom	QN1	Bi-flow valve
	Heating	High T	DH primary	90	45	GP1	Variable speed pump
EXTRACTION BILTST	Heating	Low T	BILTST primary	90	45	GP2	Variable speed pump
INJECTION SUPPLY	OFF	High T	BILTST secondary	120	50	QN2	Three way valve
	Cooling	High T	HP hex primary	90	45	QN3	Three way valve
	Cooling	OFF	HP hex secondary	90	40	QN4	Flow control valve
	Cooling LT	High T				-	Flow meter
INJECTION RETURN	OFF	Low T					
	Cooling LT	Low T					
	Cooling HT	Low T					
	Cooling	OFF					

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1.3.2. 3FS in ULTDH and nZEB with BILTST and Microbooster.

When the 3FS is placed in locations with nZEB buildings supplied by ULTDH the following layout and operating functionality was initially proposed. In the following Figures, some functioning modes included in the design of the 3FS are shown.

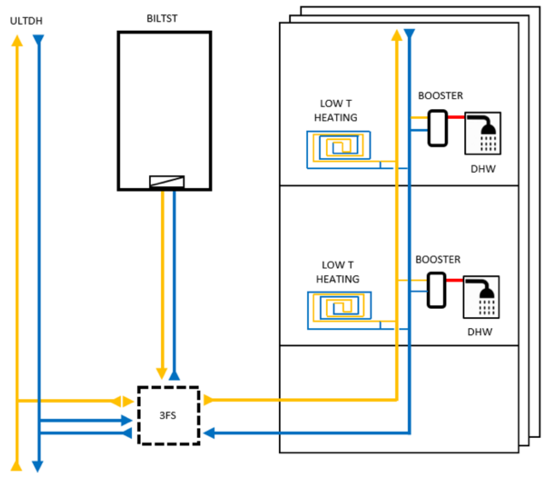

Figure 1. System flow diagram 3FS in ULTDH and nZEB with BILTST and HP Booster

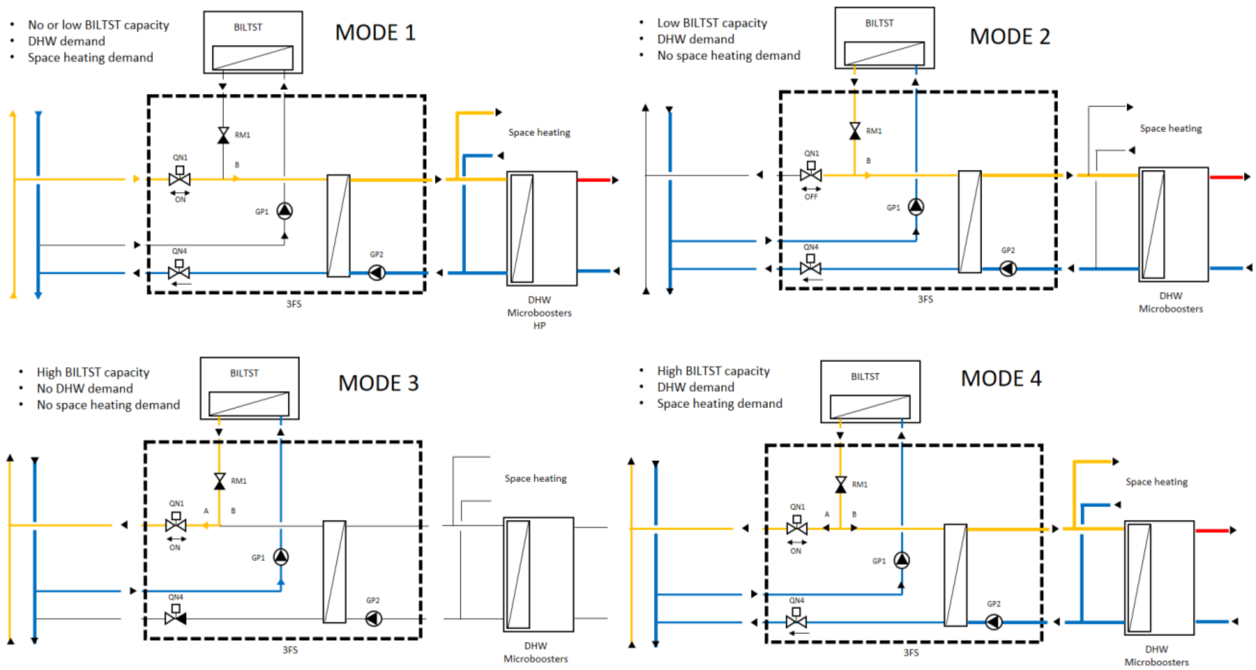

Figure 2. Operational mode 3FS in ULTDH and nZEB with boosters.

1) Mode 1: Heat from DH is used for DHW (Microbooster) and SH.
2) Mode 2: Heat from DH, in combination with BILTST is used for DHW load (and/or SH).
3) Mode 3: Heat from BILTST is injected in the supply line. No demand for SH or DHW
4) Mode 4: The two heat sources (BILTST and ULT DH supply line) are combined for satisfying DHW & DH demand

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1.4. Microbooster heat pump

A Microbosoter heat pump is a unit that extracts heat from a liquid heat source through a vapour compression cycle in order to produce hot domestic tap water at higher temperature than the heat source. The technology was introduced to allow the utilization of ultra-low temperatures heating networks and to reach the needed domestic hot water temperatures while minimizing energy consumption. The unit is composed of a built-in hot water storage tank, a heat source circuit, a heat pump circuit and a controller. The Microbooster can operate in different operating modes according to the heat source, DHW conditions and type of installations.

The booster heat pump can be connected in parallel or in serial connection to a heating system as shown in the Figure below.

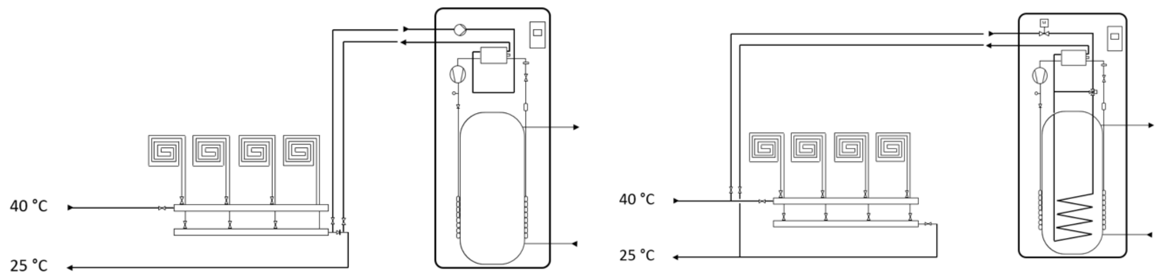

Figure 3. Installation schemes of the MBHP

When connected in serial connection to the heating system, the Microbooster allow for minimal return heat source water temperature. On the other hand, when the unit is connected in parallel connection the booster unit allow for minimum electricity consumption. In this case, the Microbooster can be equipped with a coil which allows for pre-heating of domestic hot water inside the tank, by directly using DH and without the use of the heat pump cycle. When no more heat can be extracted from the heat source, the heat pump is activated to further increase the domestic hot water temperature, up to 65 ºC.

The Energy performance of the booster heat pump was measured on a working prototype and on field test units according to tapping profiles and methodologies of standard EN16147. Domestic hot water coefficients of performance of 5.2 and 8.5 were measured for heat sources of 25 ºC and 40 ºC respectively. The unit has been tested at a recognized third-party test institute for its performance assessment.

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1.5. Demonstration sites

1.5.1. Belgrade

A district heating substation for the demonstration site of Belgrade was developed. The unit was designed to allow the operation with LTDH and a BILTST and in the specific:

1. The extraction of heat from the DH grid to supply DHW, Radiator heating and air heating.
2. DHW preheating from the BILTST system.
3. The injection of excess heat from the BILTST system to the return line.

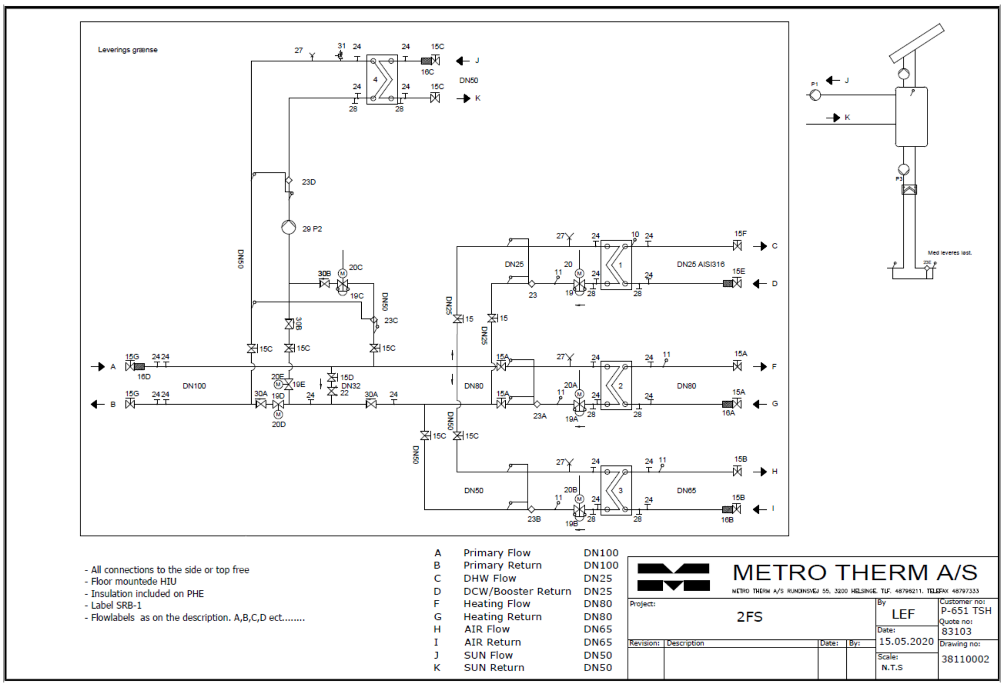

Figure 4. 2FS P&ID.

The unit will be installed in Q3 2020 at the International Primary School of Belgrade. A 3D model of the substation is presented in Figure 5.

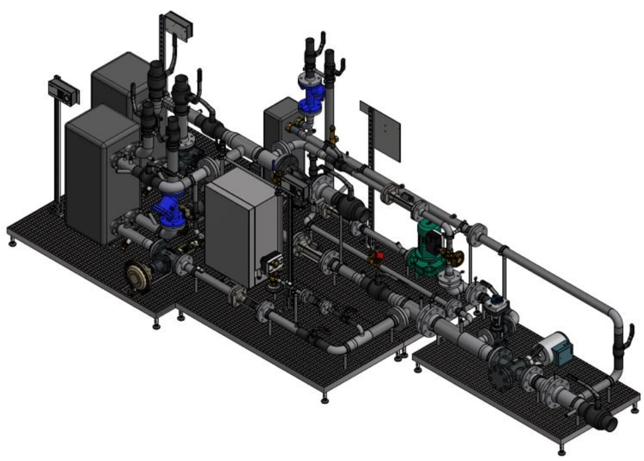

Figure 5. 2FS 3D model

1.5.2. Denmark demo site

The overall Energy Flex house demonstration site in Denmark is presented in Figure 6. In the demonstration site three 3FSs are proposed:

(1) Substation used in combination with the Microbooster (1a - 1b)

(2) Substation with the BILTST and Microbooster

(3) Substation with the DHWRHP

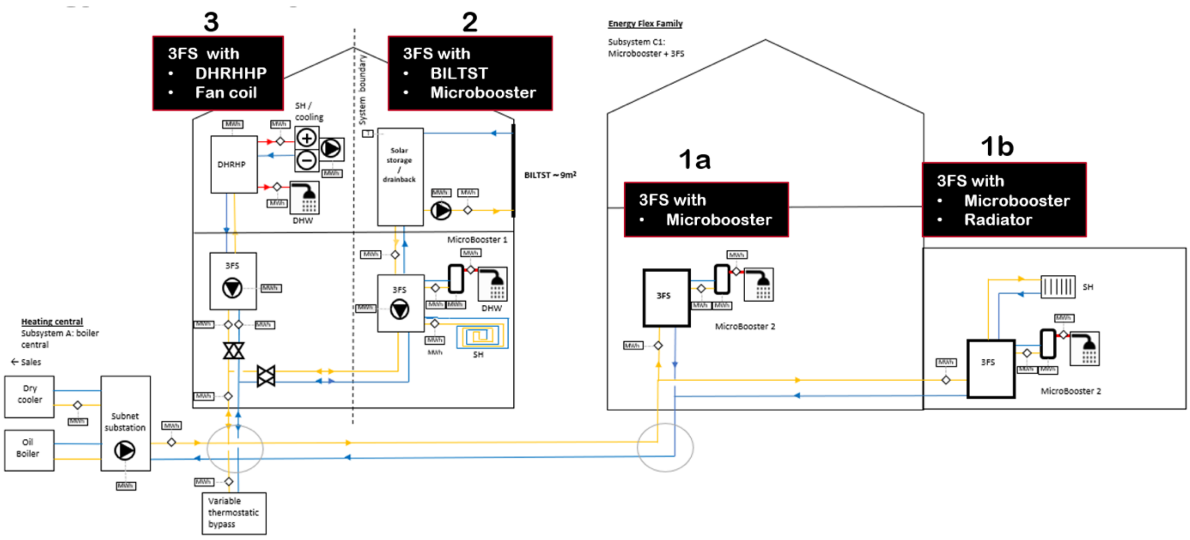

Figure 6. DTI Energy Flex House – Denmark demonstration site – Overall system layout.

The Danmark demonstration site, located in Taastrup, is composed of a ULTDH network with supply temperature of 35-45 °C at standard conditions. When heat is injected back to the ULTDH network from the BILTST or DHRHP, the DH temperature may increase.

The higher temperature, which may occur for instance in summer periods, can be exploited for the production of the DHW via the Microboosters.

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1.5.3. Substation with BILTS and Microbooster

A district substation was specifically designed and demonstrated to couple a BILTST system and a Microbooster heat pump to the ULTDH grid. Space heating is directly supplied from the ULTDH grid to a low temperature heating system and DHW is prepared by a Microbooster Heat Pump. A control strategy which assures solar heat injection to the DH flow line at has been implemented into the unit. Here below a flow diagram of the considered unit and few images from the demo installation in Taastrup.

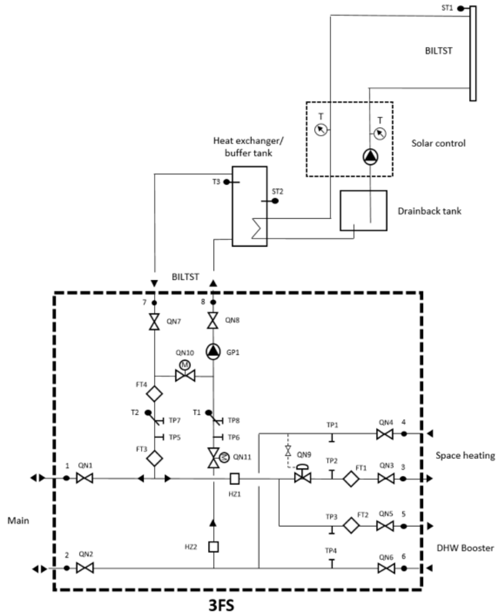

Figure 7. Taastrup substation with BILTST and Microbooster

Figure 8. Some images of the Microbooster and BILTST demonstration in Taastrup, Denmark.

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1.5.4. Substation for the integration of a DHWRHP

A district heating substation has been designed to couple a District Heating Reversible Heat Pump to the ULTDH. The unit allows the 3FS to extract heat from the DH grid as a heat source for passive space heating and as a heat source for the heat pump, which assures DHW preparation and supply of space heating.

A process and instrumentation diagram of the 3FS in combination with the DHRHP is presented in Figure 9.

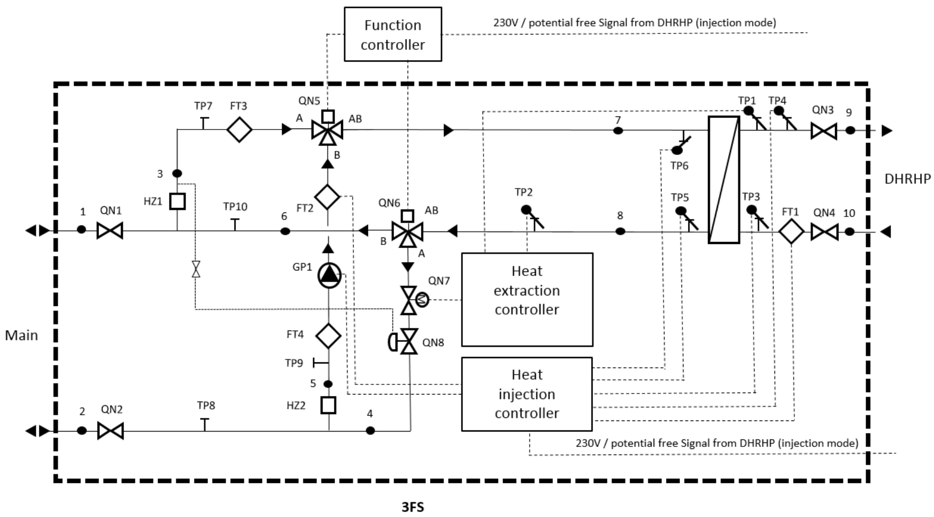

Figure 9. P&ID of the 3FS used in combination with the DHRHP.

A custom-made controller and software is being developed in order to assure a robust operation of the unit in different operational modes, both heat extraction and heat injection.

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