RELaTED

D3.5 - Publishable summary of RELaTED Technology developments

Date: 2020/07/28

Deliverable	D3.5
Name	Building integrated low temperature solar thermal systems (BILTSTS)
Website	www.relatedproject.eu
Project Coordinator	Roberto Garay. TECNALIA, roberto.garay@tecnalia.com
Author(s)	Matteo Caramaschi mca@metrotherm.dk Torben Shifter-Holm tsh@metrotherm.dk, Kasper Korsholm Østergaard kko@metrotherm.dk Ted Holm ted.holm@nibe.se David Kroon david.kroon@nibe.se Patxi Rubin, INNOMETAL patxi.rubin@innometalgroup.com Jorge Imar, INNOMETAL jorge.sanchez@innometalgroup.com Roberto Garay, TECNALIA, roberto.garay@tecnalia.com Antonio Garrido, TECNALIA, antonio.garridomarijuan@tecnalia.com Michaela Meir michaela@inaventasolar.com John Rekstad john@inaventasolar.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein

PROJECT SUMMARY

Project Acronym	RELaTED
Project Title	REnewable Low TEmperature District
Project Coordinator	Roberto Garay, TECNALIA roberto.garay@tecnalia.com
Starting date	Nov 2017
Duration in months	48
Topic	EE-04-2016-2017 New heating and cooling solutions using low grade sources of thermal energy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

ABOUT RELATED

District heating (DH) systems are one of the most energy efficient heating systems in urban environments, with proven reliability within many decades already. DHs have traditionally been designed to be operated in a hierarchized way, with central energy production facilities delivering heat to a variety of distributed consumption locations.

DHs are identified as key systems to achieve the de-carbonization of heating energy in European Cities. Renewable and waste heat sources are foreseen at the same time as decarbonized heat sources and the way to guarantee competitive energy costs with limited influence of fossil fuel supply price volatility. To achieve this, conversion of DHs is needed regarding:

- The reduction of their operation temperature to avoid current technical constraints in the integration of low-grade industrial heat sources,
- The introduction of larger shares of renewable energy sources (RES) in the DH network.
- The introduction of distributed heat sources (reject heat from cooling equipment...).
- To guarantee economic viability with the trend of DH heat load reduction due to the evolution of the building stock toward NZEB (Near Zero Energy Buildings).

RELaTED will provide an innovative concept of decentralized Ultra-Low Temperature (ULT) DH networks, which allow for the incorporation of low-grade heat sources with minimal constraints. Also, ULT DH reduce operational costs due to fewer heat losses, better energy performance of heat generation plants and extensive use of de-carbonized energy sources at low marginal costs.

The RELaTED ULT DH concept will be demonstrated in four complementary operation environments (new and existing DH, locations, climatic conditions, dimension…) in Denmark, Estonia, Serbia and Spain.

RELaTED approach will follow the strategy of the electrical smart grids, in which energy generation is decentralized and consumers evolve to prosumers (they consume and produce energy).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

Document history

Work Package	WP 3 – Subsystems		
WP Lead	Inaventa		
Deliverable	D3.5 Publishable summary of RELaTED Technology developments		
Date	2020/07/31		
Due date			
Status	Submited		
Date	Version	Person/Partner	Comments
2020/07/13	1.0	Inaventa	sent to Tecnalia
2020/07/28	2.0	TECNALIA, NIBE, Inaventa	Internal review & associated changes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

Table of contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

Acronyms

ReLaTED	Renewable Low Temperature District
EC	European Commission
H2020	Horizon 2020 EU Research and Innovation programme
PM	Project manager
WP	Work Package
WPL	Work Package Leader
TL	Task Leader
3FS	Triple Function Substation
BI	Building Integrated
BILTST	Building Integrated Low Temperature Solar Thermal
CHP	Combined Heat and Power
DCS	District Cooling System 10/15 °C
DER	Distributed Energy Resources
DH	District heating
DHRHP	District Heating Reversible Heat Pump
DHW	Domestic Hot Water
HP	Heat Pump
HT	DH High Temperature 100/50 °C
LT	DH Low Temperature 80/40 °C
nZEB	Nearly Zero-Energy Buildings
RES	Renewable Energy Sources
ST	Solar Thermal
ULT	Ultra Low Temperature
ULT	DH Ultra Low Temperature 45/30 °C

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

Table of Figures

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author’s views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

Executive summary

This deliverable report is the publishable summary of the activities carried out in WP3.

This includes 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 scenaSystem 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.

Further, **District Heating Reversible Heat Pump (DHRHP)** and its` connection schemes are described. The DHRHP system consist of one or more reversible heat pump units modified to allow for operation with heat source/sink at DH temperature. Although its primary use in RELaTED is designed for ULT DH application, the system has been designed to allow its operation at higher temperatures during the transitory period prior to ULT conversion of DHs already in operation. The connection schemes show how the ULT DH, 3FS, BILTST, and internal HVAC systems of the building are connected. These schemes are flexible to adapt to transitory periods in the overall configuration of the DH network in its conversion to LT, possible conversion of distribution systems in the building, and variations in heat loads.

Based on existing heat pumps in its portfolio, NIBE developed customized heat pump units where key elements such as refrigeration components, electrical wiring, pipe and pump design etc were modified for operation at higher source temperature.

In RELaTED **two solar thermal (ST) collector technologies** were adapted for better integration into ULT DH concepts and for ensuring optimal operation. Advantages of both technologies (Inaventa Solar and INNOMETAL) are building integration, non-pressurised design of the solar loop, introduction of water as heat carrier instead of water-glycol mixture and the drain-back principle as protection against freezing and boiling of the heat carrier.

These two BILTST collector technologies are differenced by their aesthetics and their geographic suitability. One favourable solution is that first priority should be given to (pre-)heat cold DHW with solar energy. All other energy sources should be used to reach the final DHW temperature and excess heat should be injected in the DH network -dependant on temperature level-into the forward or return side.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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

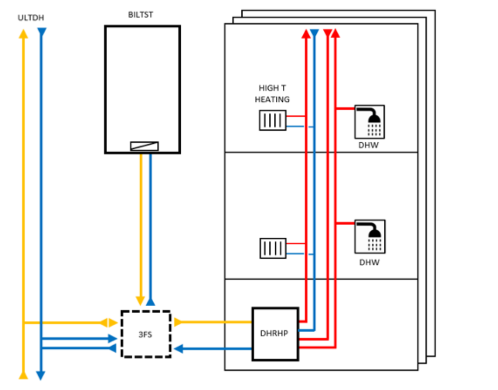
In the initial phase of the project, several unit configurations and operating functionalities were investigated. In Table 1 a summary of the conceptual proposal of a 3FS used for ULTDH in existing buildings with a DHRHP and BILTST is presented. Many more examples have been prepared and examined and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

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

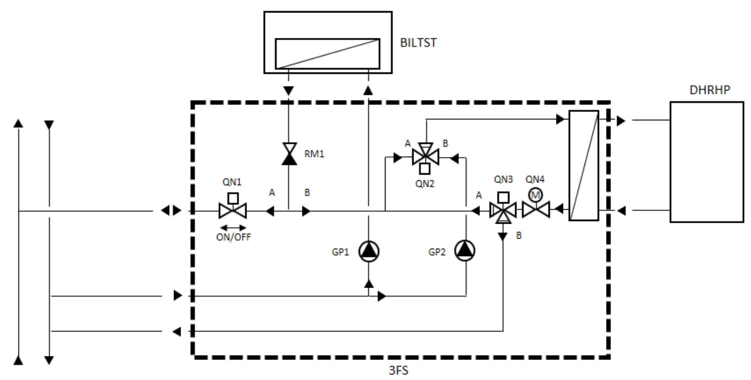
Table 1. Conceptual proposal of a 3FS used for ULTDH in existing buildings with a DHRHP and BILTST

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
EXTRACTION	Heating	OFF
	Heating	High T
EXTRACTION BILTST	Heating	Low T
INJECTION SUPPLY	OFF	High T
	Cooling	High T
	Cooling	OFF
	Cooling LT	High T
INJECTION RETURN	OFF	Low T
	Cooling LT	Low T
	Cooling HT	Low T
	Cooling	OFF

Dimensioning parameters		
Location	T max	T nom
DH primary	90	45
BILTST primary	90	45
BILTST secondary	120	50
HP hex primary	90	45
HP hex secondary	90	40

Components	
QN1	Bi-flow valve
GP1	Variable speed pump
GP2	Variable speed pump
QN2	Three way valve
QN3	Three way valve
QN4	Flow control valve
-	Flow meter

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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.

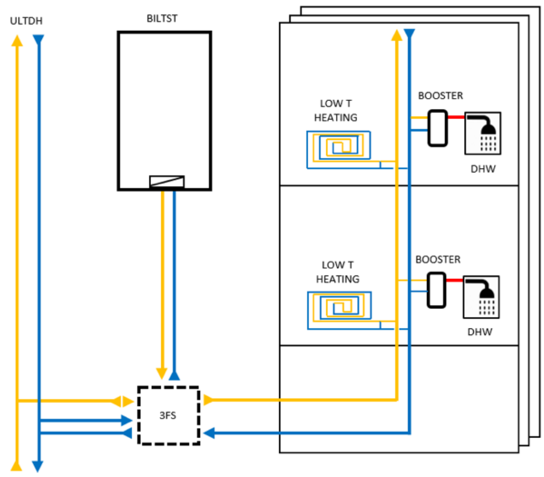


Figure 1. System flow diagram 3FS in ULTDH and nZEB with BILTST and HP Booster

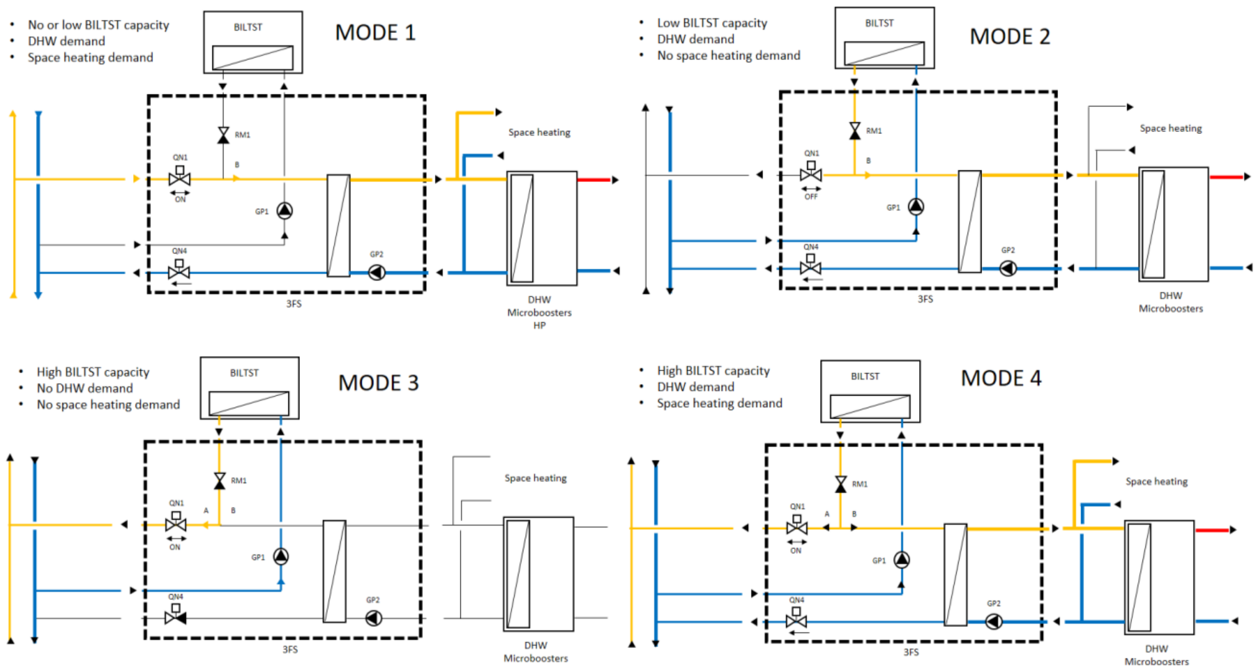


Figure 2. Operational mode 3FS in ULTDH and nZEB with boosters.

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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.

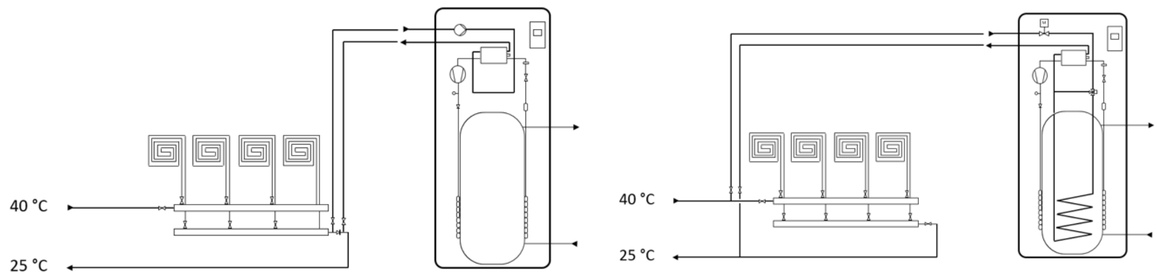


Figure 3. Installation schemes of the MBHP

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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.

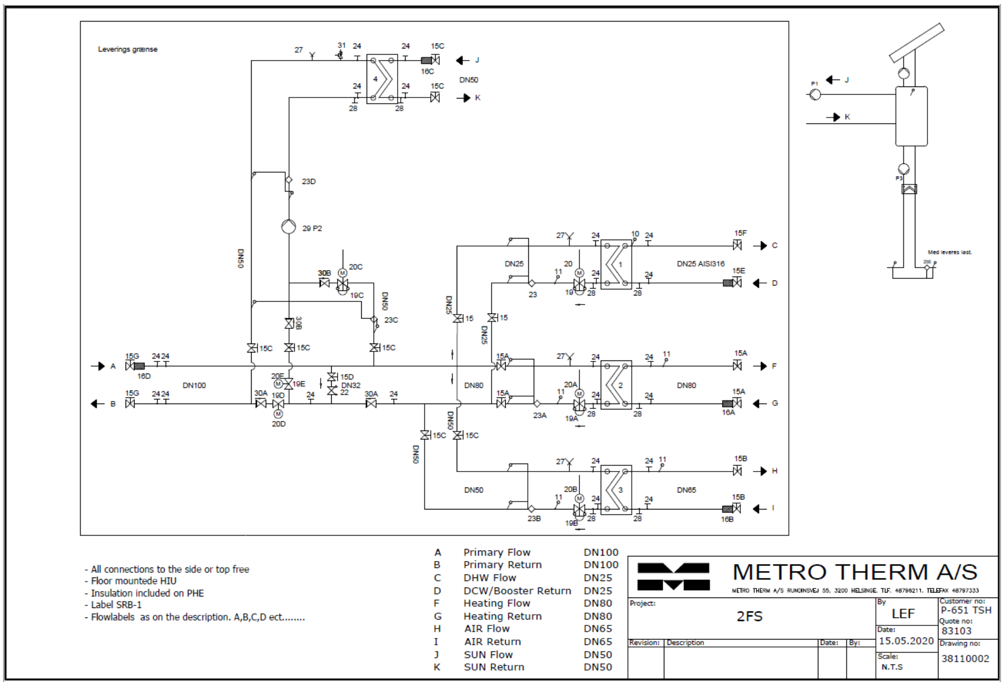


Figure 4. 2FS P&ID.

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.

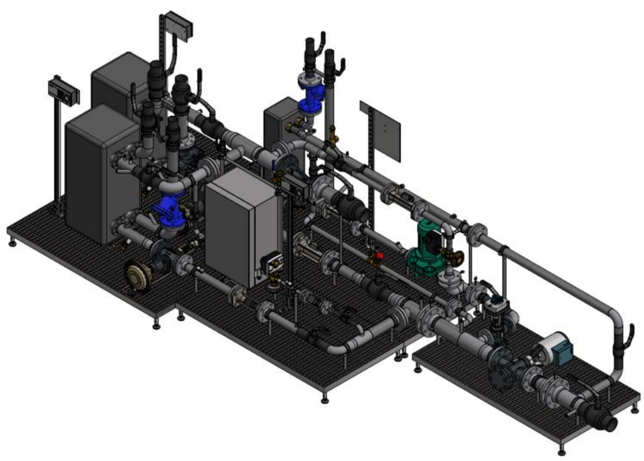


Figure 5. 2FS 3D model

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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

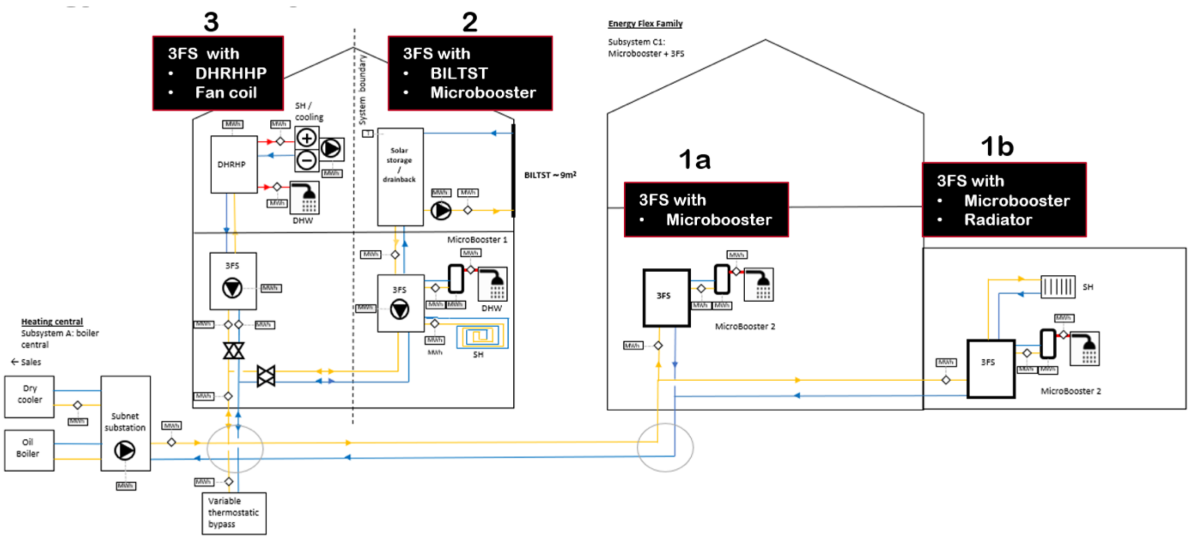


Figure 6. DTI Energy Flex House – Denmark demonstration site – Overall system layout.

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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.

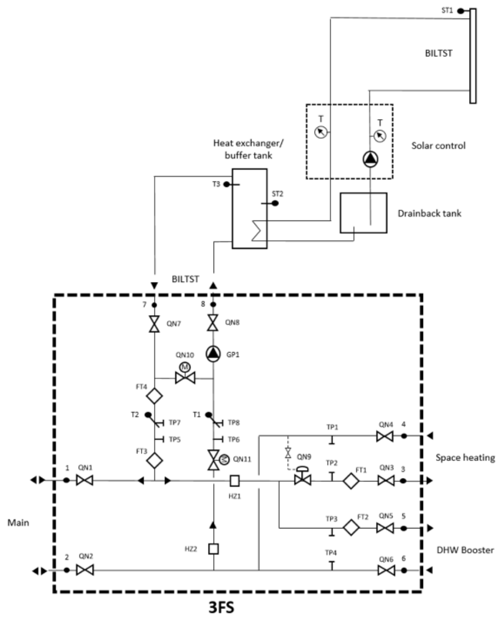


Figure 7. Taastrup substation with BILTST and Microbooster

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

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.

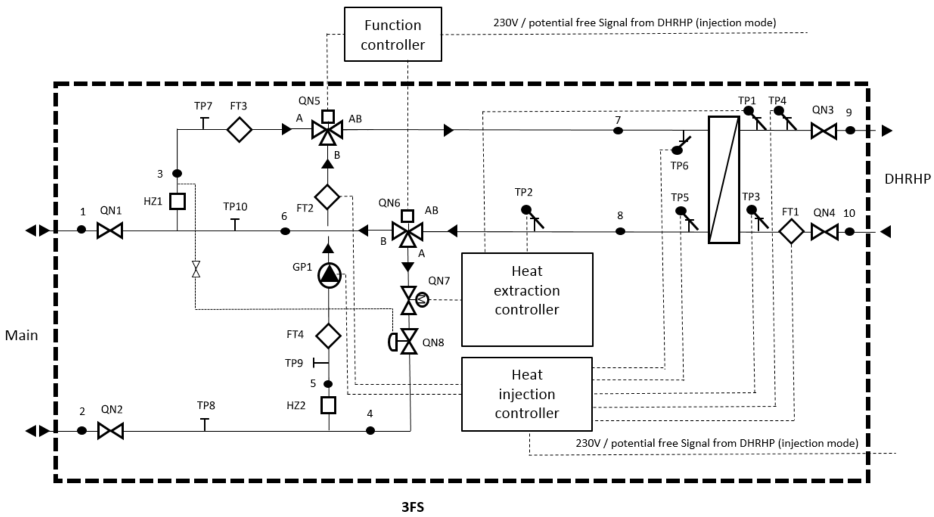


Figure 9. P&ID of the 3FS used in combination with the DHRHP.

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

2. Design of DHRHP

2.1. Introduction

With the introduction of ULT (~45ºC) DHs, critical issues such as treatment against legionella, adequacy of heat delivery systems, methods to directly inject RES into the district energy network, etc. need to be solved.

Here, the DHRHP is a crucial component in achieving these critical issues. A common denominator as a solution for all of these problems is the ability to raise the temperature level to a sufficient one, likely around 60 °C, for achieving at least 50 °C tap water temperature as well as injecting heat to the LT or ULT district heating grid. This is why the DHRHP is a key component in a ULTDH system that needs to be developed. The reason to the neccessity of a development for such a heat pump, is due to the fact that heat pumps harvesting energy at these temperature levels, are not commercially available at present date. Those heat pumps that exists today are normally custom built for some sort of energy recovery for industrial application. So, in order to make a ULTDH system more viable from both economical as well as energy efficiency point of view, a mass produced heat pump for this application need to be elaborated.

2.2. Adaption of NIBE ground source heat pump

2.2.1. Higher source temperatures

The temperature range of the heat source for a ground source heat pumps are typically 0 – 10 ℃ over the season and most ground source heat pumps on the market are designed for an incoming source temperature between -5 ℃ to + 20 ℃.

In this section, it is discussed how a heat pump should be designed to work in an ultra low temperature district heating network (via the 3FS), where ultra low temperature corresponds to 35 – 45 ℃ in the network. By having this low temperature in the DH network, the heat losses from the distribution can be decreased compared to traditional district heating systems and the possibility to inject heat to the network from renewables and process heat from industries can be utilized to a higher extent.

This lower temperature level from the DH will still be enough for providing space heating (passive), at least for new building areas, but not enough for producing domestic hot water. For domestic hot water production, a district heating reversible heat pump (DHRHP) will use the DH as heat source and produce domestic hot water to a usable temperature. The DHRHP can also provide space cooling for customers with cooling demands. When the heat pump is producing space cooling, the heat generated in the condenser will be injected into the DH network or, if there is a simultaneous need, into the domestic hot water tank if the hydraulic installation allows this.

In this type of application, the temperature levels on the source side will be much higher than what conventional ground source heat pumps are designed for, meaning the heat pump must be redesigned and optimized for this kind of installations. To make a completely new design

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

of a liquid-to-liquid heat pump requires a lot of resources. Thus, to be able to deliver prototypes with high quality and robust function to the demonstration sites, within the time frame, NIBE will base the DHRHP on some of the ground source heat pump models available on the market today.

To be able to extend the compressor envelope to handle source temperatures up to 45 ℃ and to optimize the performance at higher temperature, there is a need of evaluating or re-designing some of the components like:

- The expansion valve due to higher mass flow rates of the refrigerant (higher capacities).
- The electronics and wiring, due to higher capacities and currents.
- The heat exchangers (evaporator and condenser) due to higher capacities for keeping low temperature loss.
- Pressure drop in pipes and components needs to be verified due to a higher mass flow.

2.2.2. Safety devices

Beside the evaluation of the main components in the refrigerant cycle, also the safety devices must be considered. Normally there is a low pressure switch that detects if the flow rate is stopped on the evaporator side and a high pressure switch for the condenser side. In the district heating application when using water as heat transfer medium it is necessary to detect low or no flow rate to avoid freezing and breaking the evaporator. This could be done with a new low pressure switch with higher cut-out pressure or implementation of a flow switch which stops the heat pump if the flow rate becomes too low.

District heating systems requires normally higher pressures in the primary water side than what heat pumps are designed for at the source side. By adding a plate heat exchanger in the 3FS, where heat is supplied or extracted to the heat pump system, a lower system pressure (3 – 4,5 bar) can be used in the loop between the 3FS and the heat pump.

2.2.3. Cooling

In the scope of the project, the district heating reversible heat pump (DHRHP) shall be able to provide space cooling. Two concepts can be used for achieving cooling functionality:

- Reverse the flow of the refrigerant in the refrigerant circuit
- Switch the flows of the heat transfer medias outside the refrigerant circuit

For the demonstration sites in this project, NIBE will apply both concepts, one of each type for the different demonstration sites. NIBE has already experience from both concepts. The two concepts, both have advantages and disadvantages. The main advantage of solving the reversibility within the refrigeration circuit is a more compact installation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

The positive aspects of reversing the operation with an external hydraulic module are more in numbers. Since the heat pump will control also the passive space heating from the DH to the building, there will already be a hydraulic link between the DH and the heating distribution system in the building.

Also, by switching the flows outside the refrigerant circuit, the heat exchangers will have a good thermal performance (counter current flow direction) in both heating and cooling mode. Reversing the refrigerant circuit means co-current heat transfer during cooling mode (or heating mode depending on the design) with lower thermal efficiency since the flow direction of the circulation pumps are fixed.

Another side effect of reversing the warm and cold side outside the heat pump, is that it usually leads to a more optimal refrigerant charge for the heat pump. As long the evaporator and condenser do not have the same internal volumes and efficiencies, which they rarely have, the optimum charge will vary depending on which operation the heat exchanger is performing. This leads to fewer compromises when the flow direction inside the refrigeration circuit is constant. This improves the performance of the heat pump.

2.2.4. Controller

The controller of the heat pump will be developed for controlling the comfort of the space heating, space cooling and domestic hot water in the buildings. This requires further development of the existing built in heat pump controller for also handle the new arrangement of valves and the new operation modes etc.

2.3. Specific development of DHRHP for the demonstration sites

2.3.1. Iurreta demonstration site

The district heating reversible heat pump, DHRHP, will be developed for solving higher source temperatures, the use of water as heat source medium and controlling new subcomponents and functionalities. Together with a hydraulic module, containing a setup of valves, the heat pump, will control the different operation modes; passive space heating, space cooling, and active space heating (if the temperature of the DH is not high enough for some buildings).

The Iurreta demonstration site, is a facility for the Basque regional police force, located outside Bilbao in Spain. The facility consists of a large number of buildings where this concept with the DHRHP will be used in two of the buildings, house D and house H (See D5.1 for further details).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

The simulated design loads for these buildings are:

	Design (kW)	
	Cooling	Heating
D building	90	135
H building	40	55

The heating and cooling distribution system (which are the same) consists of newly installed fan coils. Their required temperatures at design load in heating mode, are 45°C in return temperature and 50°C in supply temperature at a room temperature of 20°C. The corresponding temperatures at peak load in cooling mode, are 12°C in return temperature and 7°C in supply temperature at a room temperature of 25°C.

The Iurreta test installation is planned to be commissioned before the winter 2020/2021. Up until now the development work for this installation has been on a conceptual stage. The heat pumps we will originate our development work from is the NIBE F1345-40 (two for building D and one for building H), see figure 10. The NIBE F1345-40 is a liquid to liquid heat pump that is built up from two separate refrigerant modules that is connected in parallel. The two identical refrigeration modules each has a nominal heating capacity of approximately 20 kW at an incoming source temperature of 0°C. The heat pump thereby has two capacity steps depending on the power demand.

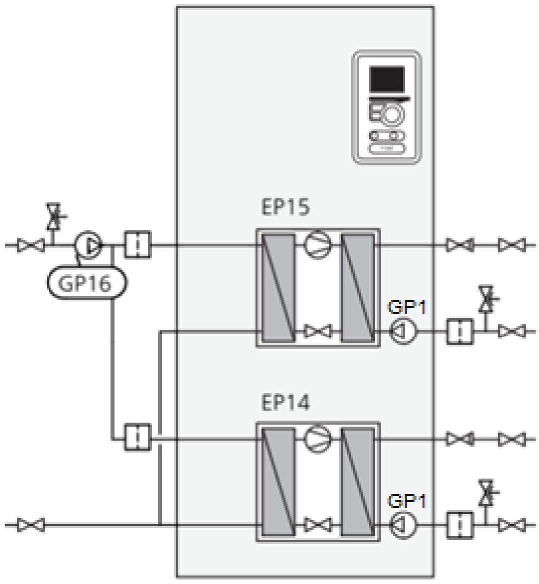


Figure 10. Appearance and hydraulic diagram of the NIBE F1345-40 which will be used for the demonstration sites in Iurreta. GP16 is the denotation of the pump connected to the cold side of the heat pump. GP1 is the designation of the pumps (one for each refrigeration module, EP14 and EP15) connected to the warm side.

In the Iurreta installation, the plan is to have a district heating supply temperature of 35°C and approximately 30 °C return temperature. At this temperature level, the heating capacity of these modules are estimated to 40 kW, meaning each heat pump can produce 0, 40 or 80 kW heating power. In cooling mode, with a 7 °C cold supply temperature, and where the heat pump will raise the district heating supply temperature from 35 °C to 40 °C, a cooling capacity

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

of 22 kW per module are foreseen. This mean for instance in building D the cooling capacity can be modulated with either 0, 22, 44, 66 or maximum 88 kW. This is considered close enough to the estimated peak power cooling demand of 90 kW.

The NIBE F1345-40 heat pump uses R407c as refrigerant with a charge of 1.7 kg per module. The planned modifications to the existing heat pump we are going to perform are: a new software to be able to control the heat pump operation and the hydraulic modules, an updated expansion valve in order to utilize a higher evaporation temperature within the refrigeration circuit (leading to a higher COP of the heat pump), new low pressure switch so freezing will be prevented (on the evaporator side of the heat pump) in case the water flow diminishes. A hydraulic connection scheme of the system is shown in Figure 11.

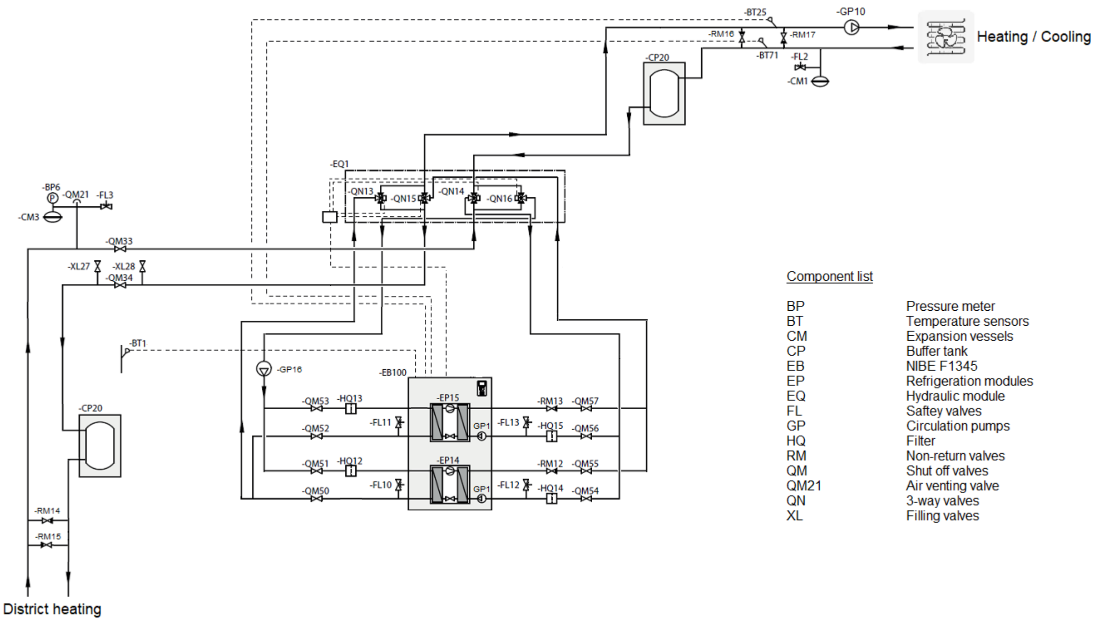


Figure 11. Hydraulic connection scheme for Iurreta building H, where the DHRHP and the hydraulic module is connected to the district heating net and the heating and cooling distribution system.

2.3.2. DTI Energy Flex house demonstration site

The district heating reversible heat pump, DHRHP, will be developed for solving higher source temperatures, the use of water as heat source medium and controlling a new internal 4-way valve in the refrigeration circuit. The heat pump, will control the different operation modes: passive space heating (with the aid of a new plate heat exchanger), space cooling, and active space heating (if the temperature of the DH is not high enough for the building) and domestic hot water production.

The DTI Energy Flex houses, is two villas belonging to the Danish Technology Institute, located at their area outside Copenhagen in Denmark. The two, two storey houses are roughly 200 m^2 each and are up for loans for visitors and staff at DTI.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

The estimated design loads for each of these buildings are:

Heating demand ≈ 4 kW

Cooling demand ≈ 3 kW

In addition to these demands there will also be a domestic hot water demand. In case the test house is inhabited, the real domestic hot water usage will apply, otherwise an automated tap cycle will be set up to simulate a real consumption. A typical tap water demand for a small family house in the Nordic countries, ranges between 1500 to 5000 kWh annually, corresponding to an average domestic hot water power of 170 to 570 W throughout the year.

The heating and cooling distribution system (which are the same) consist of a fan coil. The approximate required temperature at design load in heating mode, is 35 °C in return temperature and 45 °C in supply temperature at a room temperature of 22°C (max fan setting of the fan coil). The corresponding temperatures at peak load in cooling mode, are 15 °C in return temperature and 10 °C in supply temperature at a room temperature of 27°C (max fan setting of the fan coil).

The DTI test installation is planned to be commissioned before the summer 2020 and the solution with a DHRHP will be in one of the houses. The development work for this DHRHP has been performed during the winter 2019/2020. The heat pump we originated our development work from was the NIBE S1255-6. The NIBE S1255-6 is a liquid to liquid heat pump with a built in domestic hot water storage tank of 180 litres. This heat pump is capacity controlled by the aid of an inverter, being able to regulate the compressor frequency, so the approximate heating capacity can be varied between 1.5 to 6 kW at an incoming source temperature of 0 °C.

In this specific demonstration installation, the plan is to have a district heating supply temperature of 45°C and approximately 30°C return temperature. Since there is an intermediate plate heat exchanger in the 3FS we assume there is up to a 5 K temperature drop, meaning the heat pump will work with an incoming source temperature of about 40 °C in heating mode. In order to lower the district heating return temperature down to 30 °C, the heat pump is programmed to regulate its' outgoing source temperature to 25°C. At this temperature levels, the design capacities can be met at a much lower compressor frequency than the standard frequency range.

In cooling mode, the refrigerant circuit will be reversed via a new built in 4-way-valve and the heat pump will be able to deliver the required maximum cooling capacity of 3 kW in the middle of the compressor frequency range.

The NIBE S1255-6 heat pump uses R407c as refrigerant with a charge of 1.16 kg. The modifications done to the existing heat pump are:

- a new built in 4-way-valve in the refrigerant circuit for reversing the refrigerant flow in cooling operation
- an extra plate heat exchanger used for passive heating where the heat from the district heating will be transferred to the heating water. Together with the heat exchanger there is also a 3-way valve added, in order to be able to control active or passive heating.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

- an updated setting of the expansion valve in order to utilize a higher evaporation temperature within the refrigeration circuit (leading to a higher COP of the heat pump) and for working properly in cooling operation
- a new low pressure switch so freezing will be prevented (on the evaporator side of the heat pump) in case the water flow diminishes
- addition of condense insulation of piping and valves due to the cooling operation
- Inactivate the electrical backup in order to avoid condense issues in cooling operation
- a new software to be able to control the new heat pump operation modes and new internal components and functions

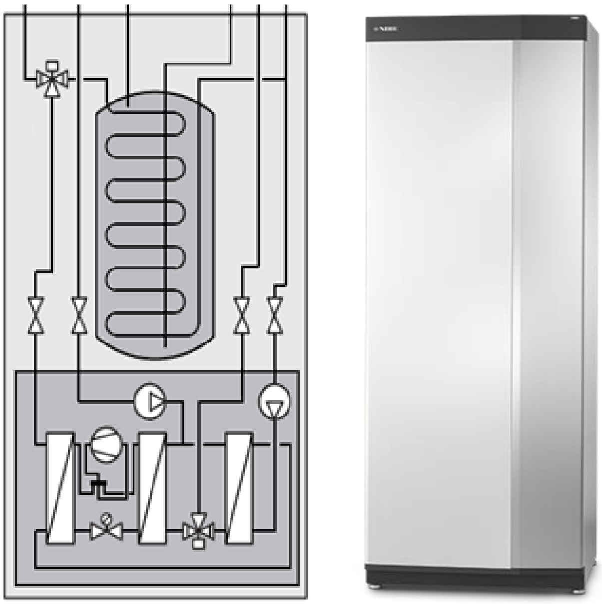


Figure 12. The modified NIBE S1255-6 for the DTI installation, prepared for additional functions as passive heating and cooling.

The new hydraulic design of the heat pump is shown in Figure 13. The adapted version is a compact solution where all necessary components for providing all operation modes are integrated in the original framework of the heat pump.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

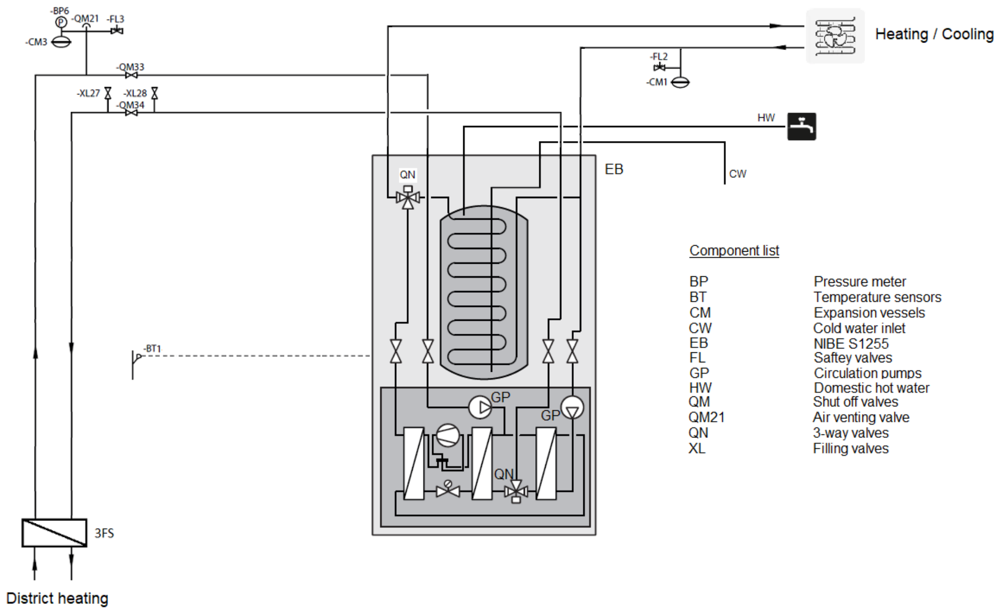


Figure 13. Hydraulic connection scheme for the DTI Energy Flex house test installation, where the DHRHP is connected to the 3FS and the heating and cooling distribution system.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

2.4. Results from the development of the DHRHP

The DHRHP that was developed in RELATED until the date of this deliverable, originated from the NIBE S1255 6 heat pump. This heat pump was redesigned, with some new features, in order to fit well into the system of the DTI Energy Flex house test installation.

The laboratory of NIBE Energy Systems located in Markaryd, Sweden is a well equipped lab facility with an expertize in testing all kind of HVAC products. The lab setup most suitable for testing the DHRHP was one of the standard test rigs for testing liquid to liquid heat pumps (see Figure 14).

Figure 14. Standard liquid to liquid heat pump test rig at NIBE laboratory in Sweden

In this kind of test rig, the flow rates as well as the temperatures of the different liquids at specified temperatures are being measured with high accuracy.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

2.4.1. Test results from active heating/domestic hot water production

The normal source temperature where the ordinary NIBE S1255 6 is optimized is 0 °C source in temperature, and a maximum tolerable temperature of 30 °C (continous).

In this application where the source temperature in to the heat pump is expected to be around 40 °C a new expansion valve setting was neccessary in order to enhance performance at this higher source temperature as well as keep within the compressors boundary limits.

In the following described lab measurements, all temperatures into the heat pump was fixed to 40 °C, and the outgoing temperature on the source side was being regulated to 25 °C. The warm side of the heat pump was varied at two levels 35/45 °C in return temperature and a fixed temperature difference of 10 K so the corresponding supply temperatures were 45/55 °C.

The measured test results are summarized in Table 2:

Table 2. Measurement data in active heating mode for the DHRHP

	return/supply	return/supply
	35/45 °C	**35/45 °C**
Compressor frequency	**COP**	**Heating power [W]**
20	10,71	2764
30	10,09	4166
40	9,38	5513

	return/supply	return/supply
	45/55 °C	**45/55 °C**
Compressor frequency	**COP**	**Heating power [W]**
20	6,75	2459
30	6,98	3953
40	6,89	5331

The high values of the COP are explained by the relatively low temperature difference between the cold and the warm side of the heat pump. This means for instance, if domestic hot water is produced with 45/55°C in return/supply temperature with the typical district heating grid temperatures in this specific grid 40/25°C, at a compressor frequency of 30 Hz, a COP of 6.98 is expected. This corresponds to a energy proportion of 85.7 % from the district heating (1-1/6.98 = 0.857) and 14.3 % (1-0.857 = 0.143) from electrical energy of the total domestic hot water demand.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

2.4.2. Test results from cooling

In the measurements where the cooling performance was evaluated, the sink side return was fixed to 35 °C, the flow adjusted to a 10 K difference which consequently meant a constant 45 °C supply temperature. This means that as long as the supply temperature of the district heating grid do not exceed 45°C, this excessive heat from the Energy Flex house can be injected via the 3FS, into the supply line of the district heating grid without causing losses.

Two temperature levels from the cooling distribution system was measured, 15/10 °C and 20/15 °C (incoming and outgoing cooling flow temperatures).

The expansion valve had to be adjusted so the risk of freezing was minimized at the lowest return and supply temperature Danish condition require (15/10 °C). This means, that the evaporation temperature on the refrigerant side of the heat exchanger wall, do not drop much less than 0 °C. To make things even more complicated the refrigerant used in this specific heat pump, R407c, is a blend of hydrofluorocarbon refrigerants with a so called temperature glide of the saturation temperature. This implies, that for a constant pressure, the different proportions of this blend will boil at slightly different temperatures (typically the last molecule will boil at ≈ 5-8 K higher temperature than the first molecule).

The evaporation temperature at the highest frequency (45 Hz, which give the lowest evaporation temperature) at 15/10°C conditions were approximately 3 °C at the outlet of the evaporator. The results from the measurements are given in the diagram of Figure 15.

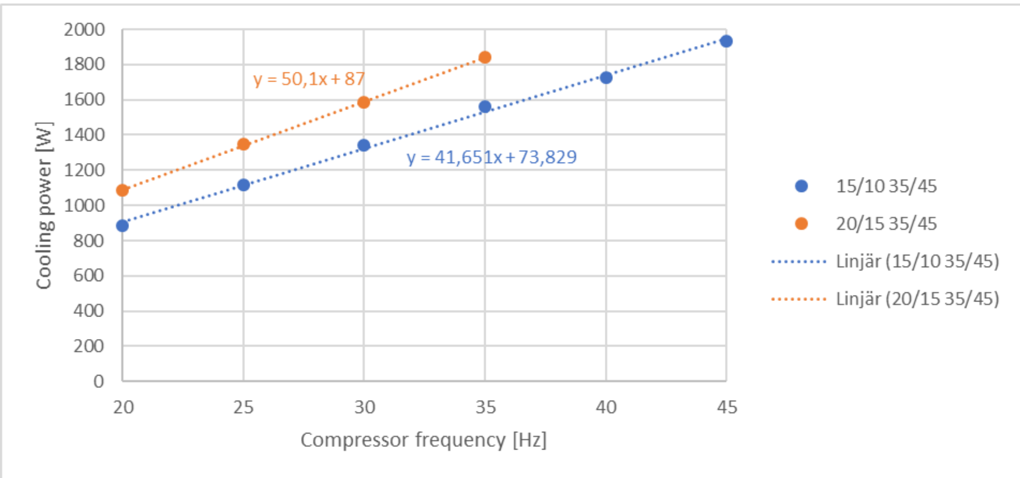


Figure 15. Measurement data of cooling power for the DHRHP as a function of compressor frequency

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

The corresponding COP or EER (Energy Efficiency Ratio for cooling performance) from the measurements are documented in Table 3.

Table 3. Corresponding COP or EER (Energy Efficiency Ratio for cooling performance) from the measurements

	return/supply	return/supply
	15/10 °C	**20/15 °C**
Compressor frequency	**$COP_{cooling}$**	**$COP_{cooling}$**
20	2,49	2,99
25	2,54	3,06
30	2,59	2,97
35	2,57	2,93
40	2,44	
45	2,44	

The relatively low $COP_{cooling}$ values in cooling mode are explained by the fact that here, the internal heat exchangers in the refrigerant cycle is working in a co-current flow, due to the reversed flow direction of the refrigerant (compared to in heating operation). This, in combination of the use of a refrigerant with blend properties, leads to a higher temperature difference within the refrigerant cycle, than the water temperature differences suggest.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

3. BILTST systems

ST energy production systems can be connected as multiple thermal energy producers/ users through a DH network to large, centralised solar thermal installations. Solar District Heating (SDH) is still in the early market development stage. Large ST plants feeding into district heating networks represent only about 1% of the installed capacity of solar thermal systems (Solar Heat Worldwide, 2018) even though they have gained increasing interest all over the world in the recent years and several ambitious projects have been successfully implemented. By the end of 2017 about 300 large-scale solar thermal systems (>350 kW_{th}; 500 m²) connected to district heating networks and in residential buildings were in operation with an installed capacity of 1140 MW_{th}. In the long run, solar district heating could represent 4-15% of the total technical potential of solar thermal energy (IEA SHC Task 55).

This report aims to provide a description of building integrated low-temperature solar thermal systems (BILTST) and their demand specifications. The report is based on the activities carried out in Task 3.1 of Work package 3 in RELaTED, where the development of BILTST systems is performed.

3.1. General aspects

In RELaTED two BILTST collector technologies are developed for integration and optimal performance in ULT DH concepts. The two technologies are differenced by their architectural design and their geographic suitability:

- The **Inaventa Solar BILTST collector,** which is a so-called glazed collector, where the collector cover prevents heat losses to the surrounding and has preferred application in colder climates or climates with cold winter.
- The **INNOMETAL BILTST collector** has no collector glazing, which makes it a simpler and less costly design and made for application in climates with moderate ambient temperatures during the cold season of the year.

3.1.1. Building integration

Inaventa Solar's and INNOMETAL's solar thermal technologies are designed for integration in the building envelope. Here the solar collectors replace conventional building skins and have the double function protecting the building from seasonal, climatic and environmental impacts and producing renewable energy at the same time. Figure 16 shows examples of building integrated collector facades from Inaventa Solar and INNOMETAL.

Building integrated low temperature solar thermal (BILTST) systems are favourable because:

- BI is cost and material saving, in particular for new-built projects or when the rehabilitation of the building envelope is planned because of replacing conventional roof/facade and insulation materials with solar collector modules.
- BI is cost and material saving because energy is produced where the consumer lives.
- BI gives aesthetic solutions: Size of the collector field is adapted to the available area on the building surface. The collector surface is in plane with the building envelope. Aesthetic solutions inspire decision makers and increase renewable energy production.
- BI reduces heat losses and better performance of the collector.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

- BI is in line with urbanisation of daily life: More and more people life in cities where renewable energy has to be produced.
- BI solar collectors do not use space needed for farming, etc.

Figure 16. Building integrated solar collector facades: Inaventa Solar technology (left) and Innometall (right)

3.1.2. Water as heat carrier and hydraulic system design

The hydraulic designs of the solar collector concepts developed in RELaTED differ significantly from those of conventional solar collector systems. As high-lighted in Figure 17 the overall design is less complex and more straight-forward.

No antifreeze additives in the solar loop - In both Inaventa Solar's and INNOMETAL's system designs pure water without additives is used as heat carrier in the collector loop, which has several advantages: Higher heat transfer because of the larger heat capacity of water relative to water-glycol-mixture, lower maintenance costs and the impact on the overall system design, making it simpler with fewer components, reduce system and installation complexity and costs (IEA SHC Task 54, Info Sheet B02 and B03)

Drain-back function as built in safety - The drain-back design of the solar loop is a built-in protection against collector stagnation during summertime (availability of solar energy and no heat demand) and freezing of the heat carrier during wintertime.

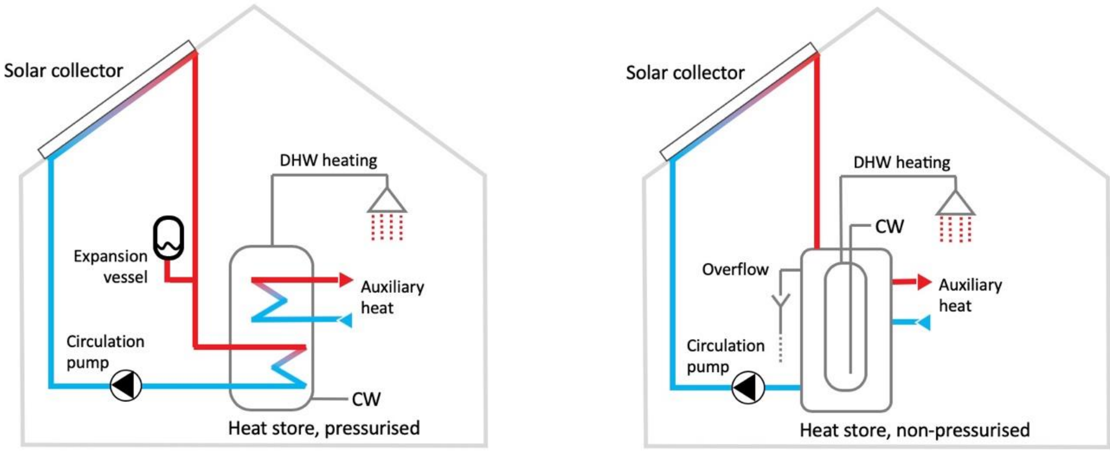
Solar loop non-pressurized - As a part of the overall design, the solar loop of Inaventa Solar's and INNOMETAL's concept is non-pressurised and a "closed system" as such. Hence there is less thermal and mechanical impact on all system components, reducing material use and costs. In particular for the installation of the solar roof, no authorised HVAC installer is required but the work can be done by a skilled building envelope installer.

Avoiding heat exchangers - As illustrated in Figure 17 Inaventa Solar's and INNOMETAL technology avoid heat exchangers between collector loop and heat store. Hence expansion vessel in the solar loop can be omitted and due to negligible system pressure, the wall thickness of absorber and solar loop piping wall thickness can be reduced.

The non-pressurised heat store in Figure 17 includes an immersed stainless-steel tank for heat transfer to DHW. This function can also be performed by a heat exchanger. The heat store has an aperture, which is open to atmospheric pressure and has also the function of a drain-back tank.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

Conventional ST technology | **BILTST technology in RELaTED**



Pressurised solar loop - "closed system"
- water-glycol mix as heat carrier in collector loop
- pressurised collector loop and heat store
- heat store contains DHW
- heat transfer through heat exchangers

Non-pressurised solar loop - "open system"
- pure water as heat carrier in collector loop
- non-pressurised collector loop and heat store
- heat store contains system water
- no heat exchanger between collector loop & heat store; tank-in-tank system for heat transfer to DHW

Figure 17. Comparison of a pressurised solar loop "closed system" and non-pressurised solar loop "open system" on the examples of a solar DHW system (simplified).

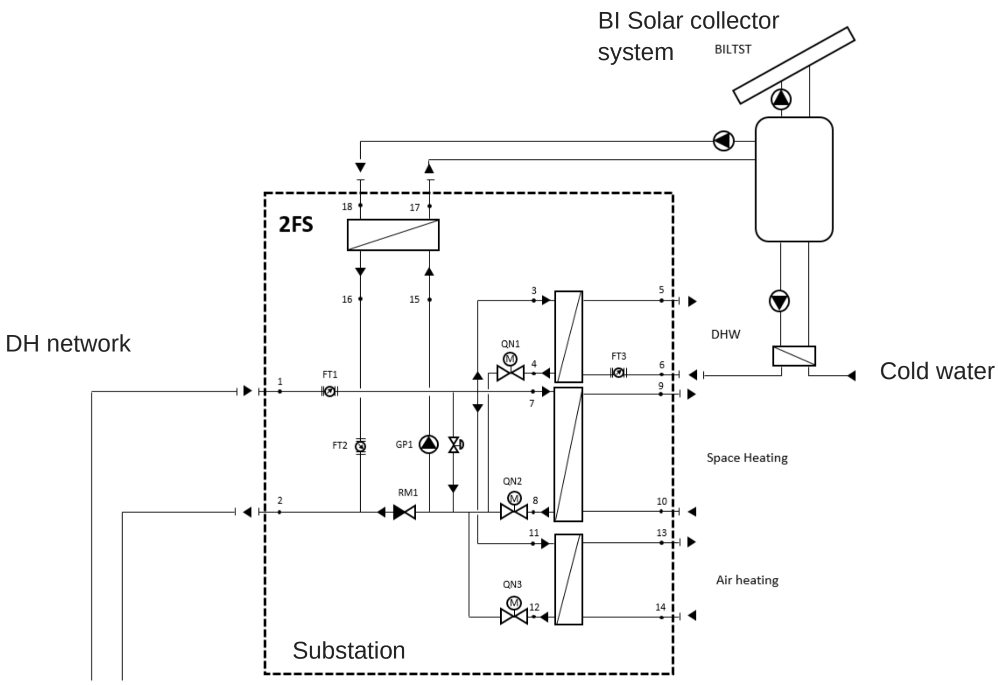


Figure 18. Hydraulic scheme shows how the substation and the BI solar collector system are interconnected to the DH network. and how first priority is given to DHW heating by the solar collector system.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

3.1.3. Priority for solar DHW pre-heating

One of the design criteria for the ULT DH systems developed in RELaTED is that first priority has to be given to solar (pre-)heating of domestic hot water (DHW). This means in practice that the lowest temperature level, the cold tap water, should first be heated by solar energy and the final DHW temperature is provided by the DH network or the DHRHP, if needed. This principle is illustrated in the hydraulic scheme in Figure 18. In that way the solar collector system operates at low temperatures level and hence with high collector efficiency (see Section 3.5).

3.1.4. Drain-back and system control

Inaventa Solar's and INNOMETAL's solar technology are open loop systems with water as heat carrier in the solar loop and use the drain-back function as overheat protection. The function is operated by the solar controller (typical unit by RESOL shown in Figure 19). When no solar energy can be harvested the controller stops the operation of the solar pump. Then -driven by gravity - the liquid drains back to a reservoir (heat store, drain-back tank) and air returns to the absorber. Hence it is important to secure sufficient slope of the forward and return pipes of the collector loop for good emptying behaviour and exchange of water with air in the absorber. In the case of overheating or freezing air is inside the absorber.

As standard solar pump the OEM pump Grundfos UPM3K is used either single of connected in series.

Normally the BILTST system operates remotely, regulated by the solar controller, but the series shown in Figure 19 (and used for the RELaTED demo projects) is compatible for connection to a central operational monitoring system (BACnet or others).

Figure 19. OEM Solar Pump UPM3K (Grundfos) and standard solar controller by RESOL

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

3.1.5. Two-phase flow, lifting height, drain-back tank

The drain-back system is in fact a two-phase flow system since the absorber, the pipes between collector and the store transport the liquid as well as air/vapour. The installation must secure free transport of air between the store and the absorber (no water traps), the dimension of the pipes must secure a flow speed v of the heat carrier that is sufficient for transporting air-bubbles from the collector and down to the store (v > 0.6 m/s).

The drain-back system puts constrains on the placement of the heat store. It must be placed at a lower level than the bottom end of the solar collector field. The pipes must be mounted without any air locks so that water can drain completely out of the absorber and air flows freely up from the top of the heat store (double function as "drain-back tank") to the collector. See example in Figure 20.

When water is pumped into an air-filled solar collector, the pumping power must be sufficient to lift the water from the top of the heat store up to the highest level of the collector field. As soon as the collector and the pipes between the collector and the heat store are filled with water, the pumping power can be reduced due to the siphon effect. In order to save electric pumping energy, a speed-controlled pump is recommended. In high buildings (where h>10 m from heat store top to collector top) an additional drain-back tank can be mounted at a higher level than the heat store in order to save pumping power.

̇he minimum volume of the drain-back tank /heat store is the volume of liquid required to fill the collectors and pipes during operation plus the pre-pressure, which the solar pump requires for operation.

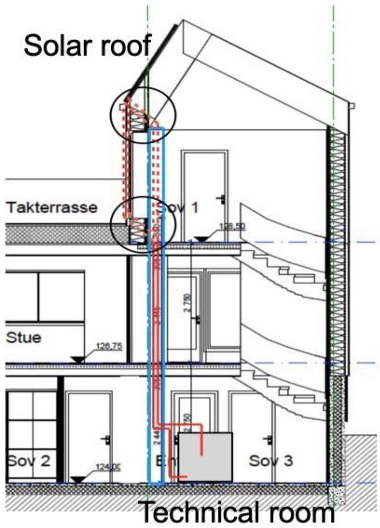


Figure 20. For both examples the location of the technical room is favourable relative to the collector installation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

3.2. Inaventa Solar concept

The Inaventa Solar collector technology, a glazed, modular solar collector concept for building integration with major components in polymeric materials and following characteristics:

Building envelope modules - The Inaventa Solar collector is designed for building integration and delivered as building envelope module, replacing regular roof or façade covers and producing heat at the same time. The dimensional flexibility of the Inaventa Solar collector opens for solar surfaces that can be adapted in size to the actual parts of the building which are available. The availability in various dimensions, simple, non-pressurized hydraulic design, using standardized plug-and play components, which are well-known to installers, together with appealing design aim to remove the barriers, which ST technology meets today.

Low weight - The use of polymeric materials gives low-weight solar collector modules, approximately 8 kg/m^2 that are easy to handle and install. There are no special equipment or cranes for installation needed than normally present at the building site.

Non-pressurised solar loop - Additionally, the Inaventa Solar collectors do not required authorized HVAC specialist but can be installed by any skilled building envelope installers. This means time and cost savings at the building site.

Low weight and large potential for cost reduction - Polymer materials together with their unique technologies for mass production are regarded as a key to realize costs reduction, built-in, multi-functional design and opportunities for aesthetic innovations. Polymers introduce low weight and dimensional flexibility as important advantages with regard to handling, transport and installation.

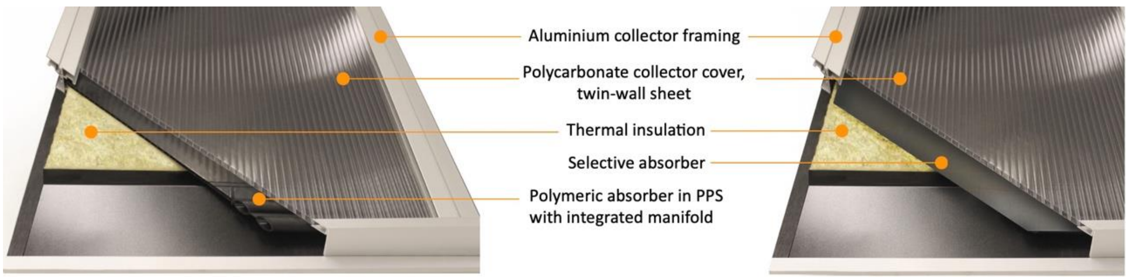


Figure 21. Cross section of the Inaventa Solar collector with polycarbonate collector cover sheet, left with PPS absorber and right with metal-based absorber.

Reduced environmental impact - The environmental impact of the Inaventa Solar polymeric collector technology has been investigated in Life Cycle Assessment (LCA) studies and compared with conventional solar collectors. The emissions to the ambient during production, transport, installation and recycling are smaller for the Inaventa Solar collector system than for the conventional heating systems (Carlson et al., 2015).

Building modules with standardized width - The modules have a standard with of 60 cm, corresponding to the standard building width in Norway (Scandinavia). The rear insulation is partly the 25 mm thick thermal insulation layer (suitable for high collector temperatures), and partly the building insulation of the main wall construction behind the collector.

The collector glazing is a transparent, twin wall polycarbonate sheet of 10 mm thickness and UV-protection layer. The mechanical strength of thin PC glazing is given by the twin-wall structure. The advantage of using polymeric collector glazing is low weight, easy handing

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

during transport and at building site and can be produced in almost any length. One important issue with the PC twin-wall sheet is the large thermal expansion coefficient in the range of 10^{-4} m/(m K). The collector framing is designed so that it can take dimensional variations up to 10 mm/m between the extreme surrounding temperatures.

3.2.1. PPS Absorber

The absorber consists of the high temperature polymer polyphenylene sulphide (PPS). Polymer materials are regarded by many as a key for realizing the large potential of solar thermal energy through cost reduction and aesthetic innovations.

Thermal conductivity - The thermal conductivity of polymers is in the range of λ=0.2-0.3 W/(mK) compared with λ=230 W/(mK) for aluminium and 400 W/(mK) for copper as conventional absorber materials. In order to compensate this substantial difference, the design is adopted. A cross section of the structured polymer sheet is shown in Figure 22.

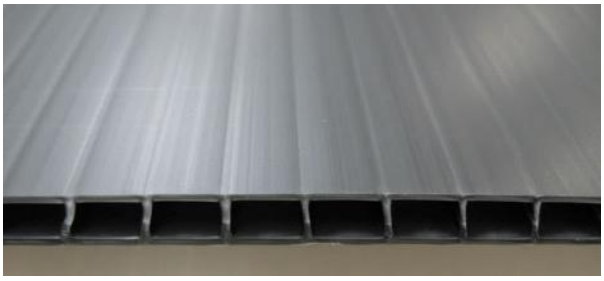


Figure 22. Cross section of a structured absorber sheet

The heat carrier is flowing through the intrinsic channels, and the solar energy is deposited on the outside. Heat is conducted through the 0.9 mm thick plastic wall, corresponding to a U-value of 22 W/(m^{2}K). The maximum heat transfer is limited to approximately 800 W/m^2 due to the solar intensity, corresponding to a total temperature difference between the two sides of the thin surface sheet of 3.6 K. Hence, the polymer absorber has a comparable, and even smaller temperature gap between the surface temperature and the temperature of the heat carrier than in a typical metal absorber.

Both forward- and return manifold pipes are integrated in the endcap at the bottom of the absorber. The absorbers manifolds are interconnected by EPDM connectors. The low hydraulic pressure in the collector loop reduces the requirements to the pressure and temperature the pipes have to withstand. An additional consequence is that skilled building workers, not necessarily authorized HVAC installers, can do the installation. This represents a substantial saving potential due to logistics in the building process.

3.2.2. Alternative absorber

Inaventa Solar's BILTST collector design exists also in a version with metal-based absorbers with selective coated aluminium sheet and serpentine copper pipe underneath (Figure 21). The outer design and the function as drain-back collector in a non-pressurised collector loop are equal to the collector version with PPS-based absorber. This absorber exists in two lengths and the combination to longer collector modules are possible.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

3.3. INNOMETAL solar collector concept

The main characteristics of the INNOMETAL BILTST system are:

Low system temperature - high efficiency - TECNALIA, partnered by NIBE has developed and successfully prototyped unglazed ST collectors for integration into combined ST - heat pump systems. The main advantage of these ST collectors is its operation at low temperature as a heat source for heat pumps, allowing for substantial performance improvement of the ST collector due to reduced heat losses. The unglazed ST collector system is conceived as high-gain ST system, which, by operating at low collector temperature minimizes heat transfer to the surrounding air. This technology targets at warm and moderate climates. The thermal insulation layer is ROCKWOOL ROCKPLUS E-220.

Building envelope modules - The ST façade system is an industrialized, all-metal building envelope where unglazed ST collectors are highly customizable for an optimal fit to the architectural aesthetics of the building (examples in Figure 23). One strength of this solution is that not all the façade has to be functional. It can be installed where necessary and the rest could be covered with dummy panels so that the overall outer design of the building is homogeneous.

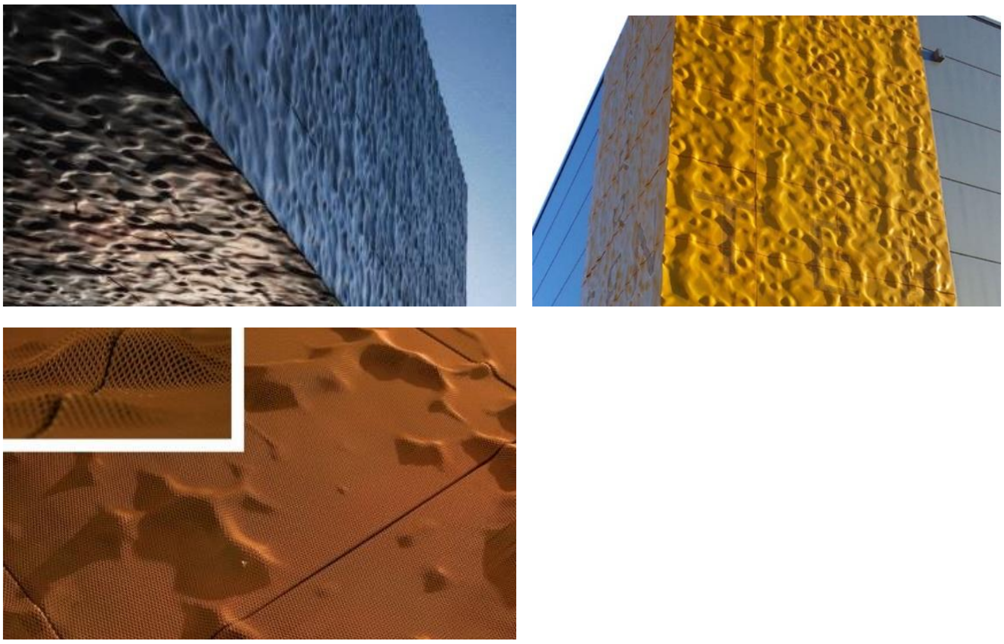


Figure 23. INNOMETAL solar collector concept, highly customizable for an optimal fit to the architectural aesthetics of the building. Top, left: Bus station in La Laguna, Spain. Top right: Organic parking façade in Barakaldo, Spain, bottom, left: Madrid Caixa Forum, Spain, botom right: Musikene – San Sebastian Music School, Spain.

Straight forward system control: The operating principle of this unglazed solar collector system is very simple: Sun heats the surface of the metallic panel cover and then by conduction it transfers to the water flowing through pipes in contact with the metal at the back.

Corrosion resistance through pre-galvanized steel - The current cover of the collector is a 1 mm - pre-galvanized steel sheet with stamp or corrugated pattern. The choice of using of galvanized steel or aluminium is connected to corrosion resistance is needed in metallic façades. Not all the patterns stamped could do in aluminium. The pre-galvanized steel is

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

more efficient than the aluminium for this kind of application where the metal is in contact directly with the polymeric pipes.

Coatings improving efficiency - In its own tool workshop INNOMETAL is able to develop a bespoke solution for each project in terms of aesthetics which is one of the strengths of this BILTSTS. This characteristic could be improved by covering the metallic surfaces with powder coatings in any colour but preferable a dark one to increase the efficiency of the system.

3.4. Installation of BILTST

3.4.1. Building integration strategy

Both BILTST collector concepts developed in RELaTED, operate under a negligible hydraulic pressure, so the handling and installation do not require authorized heating installers or plumbers, but can be installed by qualified roof or facades builders. Common design and construction processes are partnered by building & construction companies for larger construction or retrofitting projects.

The INNOMETAL technology is developed for middle and Southern European climates, as a non-glazed solution with reduced thermal losses. Inaventa Solar's technology is preferably installed in middle and Northern European climates, where the collector glazing prevents heat losses during the colder and sunny periods of the year/ heating season.

3.4.2. Glazed BILTST: Inaventa Solar

The photo series below illustrates the facade integrated installation of the Inaventa Solar BILTST collectors in a new-built school at Aurskog Høland in Norway. The collector facade is integrated in the roof-top annex, which includes technical installation for ventilation

Figure 24. Step-by step installation of the Inaventa Solar BILTST collector facade (from left to right: collector frame profiles mounted with a c-c distance of 60 cm on facade base1, then KNAUF thermal insulation boards; solar absorbers are placed in-between the frame profiles; right: Collector facade almost finished: Collector glazing is kept in place by frame profiles.

[1] Roof or facade base vary project depending; here: thermal insulation boards, type REDAir® FLEX from Rockwool

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

3.4.3. Un-glazed BILTST: INNOMETAL

The BILTST concept by INNOMETAL is very similar to de INAVENTA SOLAR concept. But as added feature the INNOMETAL concept allows a large variety of building envelope surface designs. After the definition process of the modules and pattern, the standard solution to install an INNOMETAL non-glazed BILTST system into the façade is to hang on the panels from a U profile fixed to the existing façade surface with some anchor bolts (mechanical or chemical, Figure 26). Due to the flexibility of the metal panels conformation, different formats and modulations are possible. INNOMETAL BILTST collectors demonstrate good aesthetic integration into the building envelope.

"On-site mounting - This option is preferred when the surface of the façade is irregular and using standard dimensions panels would be too complicated: First the upright profiles are mounted, then the insulation layer covering the surface of the façade, connecting the polymeric pipes to the metallic panel and fix the metallic panel cover.

Pre-mounted installation - This option is preferred when the surface of the façade is large enough so that the number of similar panels can be optimized. Here the panels are pre-mounted off-site in a workshop and then sent to the construction site to be hang on the upright profile. Pre-mounted installation reduces the installation time considerably and the finish of the panels will be more accurate. In this case, it is important to have the joining between pipes well designed to avoid leaks.

3.4.4. Construction and Testing

The fixation of INNOMETAL BILSTS to the façade is made by U and Ω profiles screwed to the main façade, and the BILSTS are directly hanged with barrettes (Figure 26). Sometimes additional supports or adaptors are needed to maintain the stiffness and the plain of the façade. This protocol can be used for every option.

Figure 25. 1st prototype. Stamped panels with cupper pipes at the back. 2nd prototype. Corrugated panels with polymeric tubes at the back. 3rd Assembly of INNOMETAL's BILTST collector modules.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

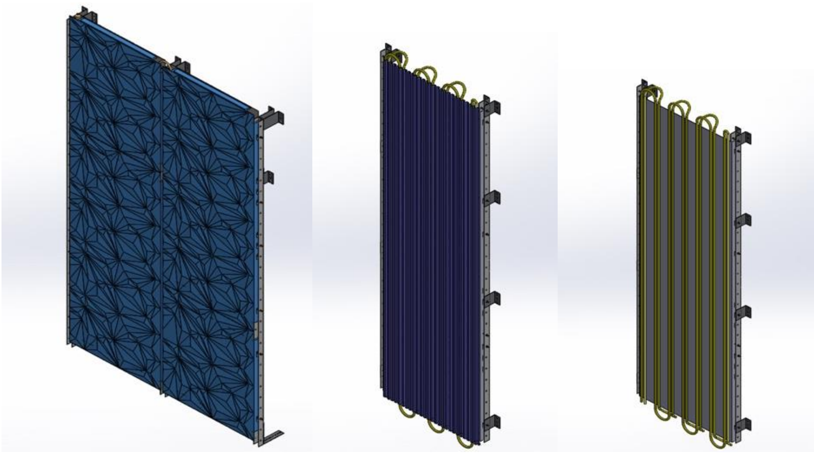


Figure 26. INNOMETAL BILTST option module, graphic seen from the front. (corrugated panel in/out).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

3.5. BILTST collector performance

The collector performance parameters, as defined in the European Norm EN 12975-1 and shown in Equation 1. These were used to plot the efficiency curves for two versions of the glazed Inaventa Solar BILTST collectors and for four unglazed INNOMETAL collector versions and are shown in Figure 27 for a solar irradiance of G=1000 W/m^2 and ambient temperature T_a=20 °C.

The possible operating ranges of the collectors connected to LT and ULT DH networks are simplified indicated by the arrows in Figure 27. It exhibits that a temperature reduction of the mean collector fluid T_m has a major impact on the collector efficiency and solar energy production. With good hydraulic system design, giving first priority domestic hot water (DHW) pre-heating, the collectors will operate with a high efficiency in particular unglazed collectors (Innometal 1-6).

Equation 1 $$\eta = F_R(\tau\alpha) - a_1\frac{(T_m - T_a)}{G} - a_2\frac{(T_m - T_a)^2}{G} = \eta_0 - a_1\frac{\Delta T}{G} - a_2\frac{\Delta T^2}{G}$$

where

η	Collector efficiency
α	Absorptance of absorber
τ	Transmittance of collector cover (glazing)
η_0	Conversion factor
a_1	Heat loss coefficient at (T_m - T_a)=0
a_2	Temperature depending heat loss coefficient
T_m	Mean temperature of heat transfer fluid
T_a	Ambient or surrounding air temperature
G	Hemispherical solar irradiance

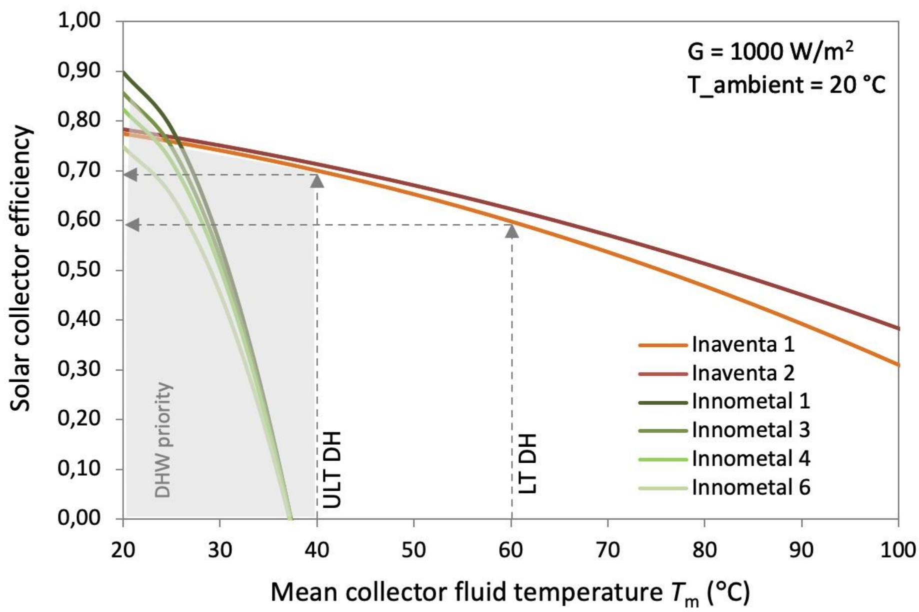


Figure 27. Solar collector efficiency as a function of the mean collector temperature Tm. for a solar irradiance of G=1000 W/m2 and ambient temperature Ta=20 °C. The possible operating range of collectors connected to LT and ULT DH networks is indicated.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.

References

Carlsson B., Persson H. Meir M., Rekstad J., 2015. A total cost perspective on use of polymeric materials in solar collectors – Importance of environmental performance on suitability. Applied Energy 125 (2014) 10-20.

Meir M., Rekstad J.Holtebu E., Meir G., 2010. Effects of Climate Change on the Heating and Cooling Demand of Buildings in Norway Towards 2050 - Calculated with SolDat v.v.12.2.0. University of Oslo, Department of Physics and Aventa AS, Oslo.

Ingebretsen, 1992, later reviewed by Haugen (2000), developed further by Aventa AS (Meir, 2007) and extended in a master project (Holtebu, 2010).

IEA SHC Task 55 - Towards the Integration of Large SHC Systems into District Heating and Cooling (DHC) Networks, http://task55.iea-shc.org/

SHW-Solar Heat Worldwide, 2018, http://www.iea-shc.org/solar-heat-worldwide

S. Furbo, 2016. Solar District Heating in Denmark, Presentation at the IEA SHC Task 54 meeting in Stuttgart Germany, Oct.06, 2016.

Duffie, J. A., Beckman, W. A. (1991). Solar Engineering of Thermal Processes, 2nd ed., John Wiley & Sons, Inc., New York

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567. This material reflects only the author's views and neither Agency nor the Commission are responsible for any use that may be made of the information contained therein.